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U.S. GLOBAL CHANGE RESEARCH PROGRAMS: DATA COLLECTION AND SCIENTIFIC PRIORITIES

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U.S. Global Change Research Program...

HEARING

BEFORE THE

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

ONE HUNDRED FOURTH CONGRESS

SECOND SESSION

MARCH 6, 1996

[No. 49]

Printed for the use of the Committee on Science

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U.S. GLOBAL CHANGE RESEARCH PROGRAMS: DATA COLLECTION AND SCIENTIFIC PRIORITIES

WEDNESDAY, MARCH 6, 1996

U.S. HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE,
Washington, DC.

The Committee met at 10:07 a.m., in Room 2318 of the Rayburn House Office Building, the Honorable Robert S. Walker, Chairman of the Committee, presiding.

Chairman WALKER. We will proceed to the purpose for today's meeting of the Full Committee.

First of all, I want to begin by welcoming the witnesses that we've called before the Committee today and thank you for participating in what I hope will be a good overview of the whole question of the Mission to Planet Earth program.

Over the past 14 months, there have been countless times that people have taken it upon themselves to theorize about this Chairman's motivations with regard to Mission to Planet Earth. Theorize isn't exactly it, though. It's amazing how people have stated with absolute conviction what my motivations are, as if they can read my mind.

Well, sorry, folks. It's obvious to me that nobody I've heard from so far is gifted with clairvoyance. So let me today set the record straight.

This comes straight from Bob Walker. And for those of you in the room today, you have the benefit of hearing my views firsthand without the media filtering the information or without any kind of political spin.

Number one, I welcome the findings of the National Research Council and their report and commend Dr. Frieman for a job very well done. That commendation is tempered with the knowledge that Dr. Frieman and his group were specifically prohibited from considering the budgetary constraints that NASA faces.

Dr. Frieman has told me himself that he was unable to look at the U.S. Global Change Research Program and the Mission to Planet Earth within this context. Congress has the task of grappling with these programs in the context of moving to a balanced budget.

Let me say I do support pursuing a research program that obtains the best available research on the fundamental physics of global climate. I agree with the position of the Marshall Institute that what is needed is a stable base of unpoliticized research find-

ings so that scientists can make long-term plans. I emphasize the concept of a stable base.

Why? Because here is my fundamental question about the Mission to Planet Earth. Is this program sustainable in the out- years?

Under any budget scenario, NASA funding is on a down-slope in the foreseeable future. Under the budget that was submitted by the Administration last year, NASA is supposed to go down to around $13 billion by the year 2000. Indications this year are that the OMB outlook is even gloomier over the next several years.

But we don't know that for a fact because we haven't seen NASA's budget. I don't think anybody is assuming that the Administration will increase the estimate for Fiscal Year 2000.

The hard fact is that NASA is faced with a shrinking pie. Some slices of the pie are fixed. The space station requires $2.1 billion annually over the next several years. The space shuttle requires a certain amount in the billions, and the type of dramatic near-term savings that I was hoping for are not expected to materialize.

Savings will occur. But the question is can we expect it through the year 2000?

The only specific priority the Administration listed for NASA in its 20-page budget document submitted in February was Mission to Planet Earth. Mission to Planet Earth continues to increase under the Administration's estimates each year, and in Fiscal Year 2000 reaches $1.6 million.

Given the public priority that the White House has placed on Mission to Planet Earth, it would appear that the program is destined to consume an ever-increasing portion of the NASA pie.

In 1995, NASA did go through a reshaping with Mission to Planet Earth. However, any savings to be produced from that effort will be reinvested into new technolologies.

I have no quarrel with investing in the technologies necessary to pull the program into the 21st century. Nonetheless, the budget for the Mission to Planet Earth is still $1.6 million in the year 2000.

How do we plan now for a post-2000 NASA budget that maintains a balance among the priority missions of NASA?

The Mission to Planet Earth program was initiated when NASA was expected to receive ten percent increases annually. Furthermore, it was deemed a special initiative. That is, a high priority program that would be funded above the NASA baseline. Clearly, that is not the situation that we face today, and we are left with figuring out how this special initiative will fit in a declining NASA budget.

According to last year's budget submission, space or science, aeronautics and technology is slated to take over a $700 million cut in Fiscal Year 2000. Due to the fact that the agency had such a short notice on the $5 billion cut from the White House, NASA submitted a budget with unresolved reductions in each account.

Holding Mission to Planet Earth sacred, then what do you do? What do you cut? Do you cut life and microgravity science? Not if you intend to fully carry out the mission of space station.

Do you cut space access and technology? Are you going to rob the account that provides us with the technologies of the future?

Space science—let's recall. The number-one recommendation of the Augustine Commission report was that "the civilian space

science program should have the first priority for NASA resources and continue to be funded at 20 percent."

Instead of sticking our heads in the sand and hoping that NASA can do this program on a wish and a prayer, we should be facing the hard fiscal realities of today. Just because Mission to Planet Earth has undergone three restructurings and one reshaping, should we stop reviewing a program that GAO estimates will cost $33 billion to complete?

I come back to the same question—Is Mission to Planet Earth Sustainable in the out-years?

I'm deeply concerned about the state of the current debate on U.S. global change research program. Instead of a healthy and open scientific debate, this whole thing has turned into a political circus complete with name-calling.

The purpose of today's hearing is to review the state of the science involved and to review options for fulfilling the Mission to Planet Earth mission with cheaper, faster, and better alternatives.

We have witnesses that represent all different types of viewpoints, including several witnesses who will represent the view of the Administration.

What I seek in this hearing is an open and healthy debate. We should not recoil in fear from diversity of opinion. We should embrace it.

Yesterday, I participated in a round-table discussion of two commercial space bills that I authored. It was a free- flowing discussion, with numerous criticisms and accolades for the bill. I welcome that kind of free and open exchange and I would welcome that in today's discussion as well.

Vice President Gore has been quoted as saying the greenhouse warming is "an ecological crisis without precedent in historic times," and that any dispute of this judgment is not "worthy of recognition."

At the AAAS meeting in February, the Vice President, in reference to congressional funding of science stated, "They're approaching science with all the wisdom of a potted plant." Earlier in the same speech, Vice President stated, and I quote: "Much of the power of science also comes from open criticism and communications across disciplines. Indeed, some of the most significant discoveries have emerged from the productive friction that occurs when different perspectives rub against each other and produce the spark of new insight."

I could not agree more with that statement. For those who attempt to stifle debate and ridicule those with diverse views, I would remind you that the new knowledge that is essential for our civilization's vitality is created out of the right kind of debate.

What we should be striving for is an environment of scientific integrity and freedom of inquiry.

That's what I hope that this particular discussion will be about today. I hope that we can have the kind of open discussion that gives us a better perspective on where we go, not only now, but in the future.

With that, I'd be happy to turn it over to Mr. Brown.

Mr. BROWN [OF CALIFORNIA]. Mr. Chairman, let me begin by commending you on your decision last year to commission a major re-

view of the Earth Observing System program by the National Research Council. This review was sorely needed and there should be little doubt that the results of the exercise have strengthened the EOS program and helped to reduce its cost.

Mr. Chairman, I am also slightly but not entirely reassured by your own statement that this review is not politically motivated and that you are looking forward to open discourse on this whole subject of the Mission to Planet Earth, and your basic concern is sustainability, something that I've long expressed my own concern for in many different areas.

Economic or budgetary sustainability in this case is a very important question, but one that does need to be thoroughly reviewed. And I understand that the academy rightfully doesn't think that this is necessarily the province within which their expertise is most useful.

However, I do believe that their review has contributed a great deal to understanding the scientific validity of the program and this is the area in which we can expect the greatest hope.

Mr. Chairman, I would like to yield briefly as part of my time to Ms. Harman from Los Angeles, whose district probably contains more of the work going on under this program than any other district in the United States, for a brief comment from her standpoint.

Ms. HARMAN. Mr. Brown, I thank you for your yielding and hope that the whole Committee will join me in wishing you a Happy Birthday today.

Mr. BROWN [OF CALIFORNIA]. I don't.

[Laughter.]

Ms. HARMAN. And Mr. Chairman, I really welcome your opening remarks and your invitation to free and open exchange, and want to be certain that you know that.

There was only one word missing from what you just said, and that word is bipartisan. I assume that you would wish to correct the record and insert that, too, because all of us here should be working together on the right structure for the Mission to Planet Earth program for the future.

Above your left shoulder is the statement—"Where there is no vision, the people perish"

I think we are in need of a long-term vision for the Mission to Planet Earth program. I agree with you that the long-term funding profile is one we need to address, especially as NASA's budget declines. I agree with you that better, faster, cheaper technology must play a large role in the long-term. But I disagree that we should put the short-term at risk while we reconsider or consider additionally what needs to happen in the long-term.

And specifically, I strongly support and I think the majority of this Committee and this Congress strongly supports moving without delay on the first group of EOS components—specifically, PM-1 and CHEM-1.

I understand that they are large satellites. But from everything I have learned and certainly from the keen witness of my many constituents who work on these programs, if we don't have a large testbed, we will not achieve the long-term results that are in all of our interests.

So with that I would say that I intend to work on a bipartisan basis with you on long-term funding issues. I'm excited about that. But I think that short term, we have to continue this program on the stable basis that we have already set.

Thank you, Mr. Brown, for yielding.

Mr. BROWN [OF CALIFORNIA]. I thank the gentlelady for her statement.

Mr. Chairman, I ask unanimous consent to insert the remainder of my statement in the record.

Chairman WALKER. Without objection.

[The prepared statements of Mr. Brown, Mr. Weldon, Mr. Hall, Ms. Johnson, and Ms. Lofgren follow:]

OPENING STATEMENT BY GEORGE E. BROWN, JR.

U.S. GLOBAL CHANGE RESEARCH PROGRAMS: DATA COLLECTION AND SCIENTIFIC PRIORITIES

MARCH 6, 1996

Mr. Chairman, let me begin by commending you on your decision last year to commission a major review of the Earth Observing System program by the National Research Council. This review was sorely needed and there should be little doubt that the results of this exercise have strengthened the EOS program and helped to reduce its cost.

However, I must express my profound discomfort with today's hearing. Today's hearing preempts and disrupts the work of the Academy—work you asked them to do.

I am concerned that the disruption of the scheduled Academy meeting by today's hearing is only a symptom of a much deeper loss of faith in traditional institutions which provide the Congress with objective advice. It is a symptom of some deep seeded belief that the science community itself lacks integrity and is incapable of making objective judgments.

It is no secret that legislation has been in the works to name a politically-appointed Task Force to redo the Academy's recommendations because the advice the Academy has offered so far does not conform to the prejudices of the Chair. We also anticipate that ultra-conservative think tanks skeptical of the entire notion of a Federal role in science will be tapped to write our policy for us.

Let me take a moment to put this issue in perspective. One hundred and thirty-three years ago, President Abraham Lincoln established the National Academy of Sciences to provide science advice to our nation. For over a century, the Academy and its operational arm, the National Research Council, have proved the critical link between the policy process and the scientific process.

When Congress must grapple with important policy decisions resting upon the best scientific advice, I know of no more rational process than that set in motion by President Lincoln—this is especially true now that the Office of Technology Assessment has been eliminated. We, as Members of the Committee on Science, should feel an especially solemn responsibility to respect that process and tradition.

Obviously, after we hear the results of the Academy, we are free to go our own way and to ignore their advice. We do this often. But I believe we should all be wary of replacing the role of the Academy with a managed policy process in which we simply put together some group to tell us what we want to hear to justify our actions.

My greatest fear is that today's hearing is simply intended to build an adverse record in anticipation of the next Continuing Resolution for F.Y. 96 and the Budget Resolution for F.Y. 97. If this is the case, if EOS is doomed to a relentless politically-motivated attack, I would suggest that today's hearing is little more than a charade designed to put on a good show for the public. If, as I fear, you are intent on proposing hostile legislation regardless of the Academy's work, regardless of the preponderance of scientific advice, and regardless of what is said here today perhaps we are wasting our time.

I will conclude by restating my belief that today's hearing is unfortunate. I have the deepest reservations about a process that appears designed to undercut and marginalize the Academy's advisory role. But I would also like to make clear that I and many other Members on both sides of the aisle remain genuinely interested

in the results of the Academy's deliberations and I will look forward to the completion of that work. We on this side of the aisle do not hold the view that the science community has lost its integrity and is incapable of making objective judgments. We hope that, in the end, good sense will prevail.

STATEMENT BY CONGRESSMAN CURT WELDON

COMMITTEE ON SCIENCE

MARCH 6, 1996

Mr. Chairman, thank you for holding this hearing today on global change research. I welcome our witnesses and look forward to hearing from them today.

As you know, there is a great deal of talk about global environmental change—some of it factual, some of it not—and it is useful to distinguish what we know and what we do not know. We know that certain aspects of the earth's environment are changing. We also know that the concentration of important greenhouse gases like carbon dioxide and methane have increased significantly in the atmosphere over the last 150 years from the burning of fossil fuels and deforestation.

Unfortunately, the role of the U.S. in dealing with global environmental change is somewhat limited. The current U.S. contribution to atmospheric carbon dioxide from the burning of fossil fuels is less than 18 percent of the global total, and this is further reduced by the re-growth of our forests through wise land-sue management. Looking to the year 2002, our role in the carbon dioxide "problem" will be reduced even further. This is simply a reflection of the fact that many countries with expanding populations are also expanding their industrial base and their use of fossil energy.

There are certain unavoidable consequences about the growth around the world. Carbon dioxide in the atmosphere, from the burning of fossil fuels and conversion of forests to agriculture use, will continue to increase and we are somewhat limited as to what we can do to stop it. Even if our country were to meet the proposed target for the year 2000 of holding the U.S. emission of carbon dioxide to the 1990 level, the effect on total atmospheric carbon dioxide will be minimal.

As a consequence, the pressures on the earth's environment are not likely to diminish for the next half-century; therefore, we know that we must focus on strategies that allow us to balance a reduction in the pressures on the environment with a realistic effort in mitigating unavoidable changes. Such a realistic strategy will allow us to meet and perhaps even help the world take advantage of some of the changes in the environment and climate.

We must learn to live with change, just as we have learned to live with severe storms, the outbreak of life-threatening diseases, and the ups and downs of economic activity. Living with change means that we must understand and anticipate change; therefore, our ability to predict climate and other environmental changes, whether manmade or natural, is critical to maintaining the economic well being of this country over the long term. With accurate information and advanced warning, we can adapt and preserve our economic and social well being.

I believe NASA's Mission to Planet Earth plays an important role in helping us to better deal with and understand the earth's changing environment. Again, I welcome the panelists here today and look forward to an open and honest discussion on global change and Mission to Planet Earth.

OPENING STATEMENT OF HON. RALPH M. HALL

MARCH 6, 1996

Good morning. I welcome the Chairman's decision to hold this hearing on NASA's Mission to Planet Earth. That program will make an important contribution to a better understanding of the Earth's atmosphere, oceans, and climate. Mission to Planet Earth is one of NASA's major initiatives, along with human spaceflight—the centerpiece of which is the International Space Station, aeronautics, technology, and NASA's other science programs.

While much of my personal focus on the Committee has been directed at assuring that the Space Station will be successfully developed and be a productive research facility for the biomedical sciences, I know that NASA is an agency with multiple missions. Mission to Planet Earth is one of them—it is an initiative that has spanned three administrations, starting with President Reagan's.

Dr. Sally Ride, a fine American and the Nation's first woman in space, said the following in her 1987 report "Leadership and America's Future in Space":

"NASA should embrace Mission to Planet Earth. This initiative is responsive, time-critical, and shows a recognition of our responsibility to our home planet. Do we dare apply our capabilities to explore the mysteries of other worlds, and not also apply those capabilities to explore and understand the mysteries of our own world—mysteries which may have important implications for the future of this planet?"

Nevertheless, Congress needs to continue to see that the Mission to Planet Earth Program is being carried out wisely and cost-effectively. It is no secret that NASA has been asked to make significant reductions to its planned budgets over the last few years. The NASA Administrator and all of the good people at the Space Agency have stepped up to that challenge. The overall NASA budget runouts have been cut by more than 30 percent. Mission to Planet Earth in particular has had its budget reduced from $17 billion to 7 billion.

These cuts have not been painless. One of the impacts of all of the budgetary instability has been the need to spend a great deal of time restructuring NASA's programs to fit within each revised budget. Inthe last five years alone, the Earth Observing System, a central part of Mission to Planet Earth, has been restructured, rescoped, rebaselined, and reshaped.

What are the impacts of all these redesigns and the resulting management turbulence? The Augustine Committee summed it up this way:

"At each step, contracts must be renegotiated, people reassigned, designs changed, and schedules revised. Soon, a disproportionate amount of time is spent in pursuit of these change practices instead of producing the end product itself."

I think that we should not be pennywise and pound-foolish—we can wind up wasting money in our attempts to save money. NASA has done a great deal to cut its budgets and streamline its operations—in Mission to Planet Earth and elsewhere. It is time to hold the line and let NASA get on with its job of exploring space and returning the benefits of its research to all our citizens.

Thank you.

OPENING STATEMENT

THE HONORABLE EDDIE BERNICE JOHNSON

FULL COMMITTEE HEARING

U.S. GLOBAL CHANGE RESEARCH PROGRAM

3/6/96

I thank you for recognizing me and for calling this hearing this morning, Mr. Chairman. Unfortunately, however, I do not believe that the goal of this hearing is a proper one.

During this Congress, this Committee has continually attempted to reduce needed funding for the U.S. Global Change Research Program. While I understand the skepticism of many in the scientific community regarding the existence of what is commonly referred to as global warming, programs such as NASA's Mission to Planet Earth contribute valuable data in our effort to understand our planet. Additionally, these research programs do not presuppose the existence of global warming.

NASA's Earth Observing System is a critical part of the Mission to Planet Earth, and many studies have noted the value of the program. In a 1995 study undertaken at the request of the Chairman of this Committee, the National Research Council claimed that the EOS program has been reformed to be more responsive to science, and more open to the introduction of new technology. Further, the study found that more reductions in funding could result in slips in the schedule, as well as the elimination of advanced technology development.

Nevertheless, given the statements of the Chairman in the past and the direction in which the Committee seems to be moving, and despite the position of the Administration on this issue, the Global Change Research Program is in danger yet again. I hope today's witnesses can shed some light the positive aspects of the program.

OPENING STATEMENT OF

CONGRESSWOMAN ZOE LOFGREN

BEFORE THE

COMMITTEE ON SCIENCE

HEARING: U.S. GLOBAL CHANGE RESEARCH PROGRAMS: DATA COLLECTION AND SCIENTIFIC PRIORITIES

MARCH 6, 1996

Good morning. I am delighted we are holding this important hearing on global change research.

As you know, I offered an amendment to H.R. 2405, the Omnibus Science bill, that would have allowed the Environmental Protection Agency to continue its important research into the dynamics of this phenomenon. I also offered an amendment during full committee markup to the National Oceanic and Atmospheric Administration reauthorization to increase funding for this important research.

Some on the other side of the aisle hold the view that environmental research is not what our country needs. Obviously I disagree with that notion. I believe, and I think many others on both sides of the aisle agree, that we need to have a better understanding of climate change—not only the natural forces which drive the system, but also the impact of human activity on these dynamics.

I am excited about the Mission to Planet Earth program. One of the best ways to study Earth as a whole is from space. Using this unique perspective, NASA's satellite program will help us to better understand and predict global climate change by studying how the atmosphere, land, seas, and icecaps interact as a system. Mission to Planet Earth will help us learn how human activity is influencing natural forces. By combining satellites and aircraft, we can look at all parts of the Earth's weather system and compare regional and local environmental changes with the global "big picture."

I welcome the panelists today, and I look forward to hearing their testimony.

Ms. JACKSON-LEE. Mr. Chairman?

Chairman WALKER. Ms. Jackson- Lee?

Ms. JACKSON-LEE. I'm not sure how you're proceeding, I'd like maybe a minute, and then to submit this in the record.

Chairman WALKER. I'll recognize the gentlelady for one minute. I would prefer to take the rest of opening statements for the record. We have a long list of witnesses. We have two panels with a lot of people today, and I do want to spend our time listening to the people that we've invited, if we can.

But the gentlelady is recognized.

Ms. JACKSON-LEE. With that in mind, Mr. Chairman, I will take even less than that and simply thank you for this hearing and emphasize the needed bipartisan approach to this. And also indicate, I know your extreme interest both in terms of legislation and dialogue, with respect to the targeting of NASA's Earth Observation System programs.

But I would hope that we would also reflect in the testimony today that our EOS program has certainly evolved from its original structure to one that is more responsive to science, more resilient, and more open to the introduction of new technology.

And with that, Mr. Chairman, I will ask that my complete statement be submitted for the record.

Chairman WALKER. Without objection.

[The prepared statement of Ms. Jackson Lee follows:]

OPENING STATEMENT BY CONGRESSWOMAN JACKSON LEE DURING THE HOUSE SCIENCE COMMITTEE HEARING ON THE U.S. GLOBAL CHANGE RESEARCH PROGRAMS

First, I'd like to thank the chairman for putting this hearing together. Over the past year, this committee has held numerous hearings on the issue and hopefully we can finally put the issue of our country's global climate change research program, to rest, at least for a while.

Considering the extensive debate on the changes our planetary climate may or may not be undergoing as a result of man's polluting tendencies, I should think that any effort to collect substantiative and comprehensive data on the issue would be welcomed by all sides. There have been numerous calls for our country's environmental policies to be better driven by scientific basis and I think the current U.S. Global Change Research Program and more specifically, NASA's Mission to Planet Earth offer excellent opportunities for this to happen.

Mr. Chairman, it cannot go unobserved that you have specifically targeted NASA's Earth Observation System many times in the past in both dialog and legislation. I appreciate your skepticism and concern, however this program has undergone numerous scientific and programmatic reviews and it is my belief that the program is on sound footing. I quote from the recent National Research Council 1995 review

"...the [EOS] program has evolved from its original plans to a reshaped program that is more responsive to the science, more resilient, and more open to the introduction of new technology."

According to the hearing charter, I believe that most of this committee's concerns about EOS should have been eased by this report. In addition, the report states that,

"...any further structural changes to the near-term EOS missions cause severe program dislocations. Further budgetary reductions or imposed constraints on technical options could require the elimination of key sensors, slips in schedule, loss of data continuity, and the elimination of advanced technology development that could enhance future research at lower costs."

Hence, I believe the time has come for the politicians to step aside and allow the scientists to begin their work in earnest. The environmental questions addressed by this program are important and far-reaching; the results will have a profound effect on many generations after ours. Let us heed history and remember Nero and not allow our environment to be destroyed while we fiddle away.

Ms. JACKSON-LEE. And I look forward to hearing the comments of the witnesses.

Chairman WALKER. Without objection. And the Chair would say that, without objection at this point, that any opening statements from members would be welcome in the record at this point.

With that, let me call our first panel of witnesses to the table, if we could, please.

I understand that Dr. Frieman is under some time constraints here. And so I think what we will do is allow him to go ahead and testify first and we will take a round of questions of him and then move to the other witnesses, if that will help with your schedule.

Dr. FRIEMAN. Mr. Chairman, I've rearranged my schedule this morning. I realize the importance of the issues you've raised. Berrien Moore will chair the meeting back at the academy, and I will stay through it, if you will permit me to do so.

Chairman WALKER. That's wonderful. Okay. Well, what we will do, we will revise this a little bit differently, then.

Then we will take the statements of each of the witnesses on the first panel. We would ask you to limit your remarks. Without objection, all prepared remarks will be entered in the record in their full text. And if you would summarize those, then it will give a chance for more dialogue.

As you can see, we have considerable member interest here this morning. And once the Republican Conference adjourns, I suspect we will get even more people here.

So we will ask you to give us the short, the Reader's Digest version of your views, and then we'll go to questions.

And Dr. Frieman, I will recognize you first. Thank you.

STATEMENT OF DR. EDWARD FRIEMAN, DIRECTOR, SCRIPPS INSTITUTION OF OCEANOGRAPHY, LA JOLLA, CALIFORNIA

Dr. FRIEMAN. Thank you, Mr. Chairman. And I want to thank you specifically for your kind words on our study.

As you know, I'm here representing the National Research Council colleagues who carried out the study you requested last spring on the Global Change Research Program and NASA's Mission to Planet Earth.

Berrien Moore and I cochaired it. The study included a very broad array of experts with a wide divergence of views. We briefed it to you last September and promised a follow-up, which is supposed to be taking place as we speak.

We thought, actually, that we might have done it right since we uniformly criticized everybody—the Feds, the Hill, the community, and so on and so forth.

Let me reiterate the questions that you raised for us then, briefly.

You asked about the performance of the U.S. Global Change Research Program, specifically, NASA's Mission to Planet Earth/EOS, use of small satellites, use of commercial involvement, and whether the science was of high quality and whether it was politically driven.

Before going into that, I might clarify one issue on the issue for the NRC and budget.

I did check that issue with legal counsel to see what precisely our boundaries are, and just a word on that.

We can receive budget information. We can discuss budget information. We can jump up and down and scream about it. We can do all these things. We make choices and recommendations on science with full knowledge of the budgetary impacts.

What we cannot do is simply say, spend this amount on that and that amount on the other, because then we cross the boundary of becoming a Federal Advisory Committee.

So I just wanted to assure you that we are aware of the budgetary problems and sensitive to those issues, although I cannot come back and make recommendations to you wearing my NRC hat.

At the inception of the study, we understood the background of the complexity and challenge of the underlying science, a changing social atmosphere with terms of expectations with regard to large science programs, severe downward budget pressures, concerns raised by many over the program's political neutrality, and more important in some respects, a growing awareness on the part of the scientific community that it had to take more responsibility for and greater leadership in program governance.

So these were the issues that surrounded us, if you will, as we went into this process.

To give you the mini-, micro-Reader's Digest version, let me say we broke it into three broad categories—a discussion of scientific progress, programs, and priorities; a review of program management and integration issues which we keep seeing falling off the edge of the table; and a set of recommendations focused specifically on NASA's program.

First, I think, we concluded that the quality of the program science is high. It is vital. The researchers involved go where science leads them and not where politics leads.

We understand that there is a political controversy. But in terms of the researchers themselves involved in this program, I believe that they do what is adequate, what is necessary in peer review.

This community is committed to understanding the state of the earth's environment and it's committed to its long-range goal of learning to predict the future evolution.

Now we recognize the necessity for budgetary stringency and recommending focusing resources on the highest priority issues. Basically, they're four in number:

Seasonal to inter-annual climate prediction. Here we want to improve the predictive skills. There are hints that the extreme flooding in the west and the east coast blizzard that we've experienced—that you experienced here—we in California escaped it—nevertheless, there are hints that that may be related to the kinds of phenomenon we're talking about.

Atmospheric chemistry, enhancing research on tropospheric chemistry.

Ecosystems.

Decadal to centennial climate.

I won't go through these in detail. I think you've heard these many, many times.

What is clear, however, is that there is a problem here that the science doesn't recognize whether it's NASA, whether it's NOAA, whether it's DOE, whether it's any agency you might want to name. And therefore, in order for this program to succeed out in the future, it requires—and focus it on these high-priority issues—it requires a significant interdisciplinary action on the part of the scientific community, and it requires inter-agency linkages which need to be much stronger than currently exist.

It requires for its success a high level of programmatic integration.

We expect that in the course of our discussions in the next few days, we will hear some of our responses from the Executive Office of the President and from the federal agencies on some of these issues. If we are not satisfied, as we promised you, we would do a phase two. We will continue.

On program management and integration issues, we concluded that much-enhanced collaboration and management budget program decisions.

We responded to your concerns, adopting advances in technology to improve performance and lower cost. We recommended utilizing systems and data products from related monitoring systems, such as ground-based and satellite observations and so on and so forth.

Let me then turn to EOS as sort of the centerpiece of the global change program.

We made a number of recommendations, but let me focus on what I consider the major issue, and that was the EOS Data and Information System.

It is clearly an enormous part of the budget. We, for the first time under Dr. Kennel's direction, were given a chart which showed the expenditures in detail of where all of the segments of that system, where the expenditures were made.

It is rather clear that this needs to be examined. We made very strong recommendations about a different way of approaching it, a different architecture, and opening it up to competition and opening it up to industry.

We know that as a result of those recommendations, that NASA has spent an enormous amount of time going through that in excruciating detail and we expect to hear what those results are and perhaps in Dr. Kennel's testimony, you will hear what the results of their studies have been to date.

On the Mission to Planet Earth components, we've already stated that we should move ahead with AM-1, PM-1, CHEM-1, TRMM, Landsat-7, to avoid delay and we believe minimize costs.

The other major issue we raised was the including of in-situ observations as central to EOS. We believe that NASA is addressing that, development, insertion of advanced technologies and so on.

Mr. Chairman, if you'll permit me, then, I'd like to speak for a few minutes as myself and not for the NRC, because you have raised the issue of severe budgetary pressures.

When we left the workshop last summer, we had hoped that the recommendations we made would result in savings and improvements in the program.

If you look at it, there are only four ways that we see, at least in EOS, for these savings—cut back on the nearer-term launches and centers, cut back on EOS DIS, utilize new and cheaper technologies, and rely on other data sources.

Let me comment briefly.

I am a member of the MEDEA group which is examining in detail the use of data collected by the military and intelligence agencies for environmental applications. That was started some time ago. It exists today.

I believe I can attest to the fact that the government has examined the kinds of issues you've raised and while it is promising, it doesn't map onto EOS. There can be some savings, but not a tremendous amount.

In an appropriate setting, I'm sure that we can discuss this in greater detail because it involves information at other levels of classification.

As of now, U-2 aircraft are being used. There's a recently declassified spyplane, the B-57, which is being used. At my own institution, we recently got declassified Navy GEOSAT data and mapped the oceanfloor, which the results were just absolutely spectacular.

Much of the declassified early data is being stored at the EOS data center as we speak. And it is available to the global change EOS researchers.

So I think what you're saying is absolutely correct—it is there, it is useful, it doesn't quite do what we would like to.

On the revolutionary spacecraft technologies, again, you are correct. But it is our understanding that we are at a stage in the development cycle where we need more development before we can rely on this to a larger extent. And so that is an out-year issue.

On the matter of an emerging remote sensing industry, I think you're again correct in pointing this out.

I have been briefed within appropriate proprietary considerations on the license applications that NOAA has received I think from six companies, if I'm not correct. The proprietary aspects concern the business details, et cetera, for those, and I don't know what they are.

But they include one- and three-meter visual systems and similar kinds of systems for the infrared and near-infrared, again, promising launches next year, two years, three years, five years. We're not clear when. It may contribute in the out-years, but it doesn't resolve our budgetary pressures at the moment, I'm afraid.

On international cooperation, again, I think we agree that this needs to be pursued more vigorously. There is a great deal of it going on, but more can be done.

So let me then state my conviction that the program, the Global Change Program and NASA's Mission to Planet Earth, are fundamentally sound scientific programs which we believe are of immense importance to the future welfare of our country and of the world.

We continue to believe that there needs to be a sound, balanced and well-integrated management, including the imaginative use of advanced technology in both domestic and international partnerships.

And under such a regime, I believe that a considerable savings can be found. It needs much more work than we've been able to undertake today, and I hope that perhaps you might direct us to continue that search to probe for the kinds of savings we believe are there. I thank you for your attention and the opportunity to present my conclusions.

[The prepared statement and attachments of Dr. Frieman follow:]

U.S. GLOBAL CHANGE RESEARCH

Statement of

Dr. Edward A. Frieman
Chairman, Board on Sustainable Development
Policy Division
National Research Council

and

Director, Scripps Institution of Oceanography
University of California, San Diego

before the
Committee on Science
U.S. House of Representatives

March 6, 1996

Mr. Chairman and Members of the Committee. I appreciate the opportunity to present testimony at today's hearing on Data Collection and Scientific Priorities in the US. Global Change Research Program.

I am speaking today on behalf of the National Research Council's Board on Sustainable Development (BSD), which I chair, and for the Committee on Global Change Research (CGCR), chaired by Dr. Berrien Moore III. Dr. Moore and I are serving as co-chairs of the continuing review of the USGCRP and NASA's Mission to Planet Earth. In fact, Dr. Moore is at this moment leading a meeting engaged in this effort in another part of this city, and I will be joining him in the chair immediately after my testimony. As you are aware, the National Research Council is the principal operating arm of the National Academies of Science and Engineering, and the Institute of Medicine. All of these stem from a congressional charter dating from 1863, which established the Academy as a private, nonprofit, self-governing membership corporation.

Last spring, you asked the National Research Council to study the US Global Change Research Program (USGCRP) and its largest sub-element, the NASA Mission to Planet Earth/Earth Observing System (MTPE/EOS). Responsibility for the review was assigned to the Board on Sustainable Development and its Committee on Global Change Research. Specifically, you were interested in receiving:

1. A review of scientific progress, and its implications for future activities of the programs.

2. An assessment of the observational strategy in the light of scientific progress, user needs, and new technologies,

3. An assessment of data and information management plans in the context of scientific needs, evolving technologies, and opportunities to serve economic development and public policy, and

4. An assessment of possibilities for efficiencies in convergence across agencies, integration of space based and in situ programs, increased reliance on international partners, and utilization of commercial and private capabilities.

In response to your request, and in line with our standing responsibility to review periodically the USGCRP, we convened a ten-day workshop at the Scripps Institution of Oceanography on July 19-28, 1995. The Workshop was co-chaired by Dr. Moore and myself. It brought together a broadly constituted group, including many although not all members of both the global change committee and my Board. The group also included representatives of relevant NRC groups, leaders of international research programs, and other invited scientists and technologists from academia and industry. Many of the members of the group were long-term participants in the programs under review; some were long-term and vocal critics of them. Representatives of the federal agencies provided us with a notably complete information base.

The conclusions of the meeting were discussed in draft form before the participants left La Jolla. The Committee's report is representative of the consensus of the Workshop, but also reflects extensive comments and modifications that resulted from the rigorous review procedures employed by the National Research Council to ensure the quality and integrity of their recommendations and reports.

We briefed the study's results to you in September and promised a followup. Indeed, in our view the summer 1995 study constituted but the first phase of a comprehensive review of the US. Global Change Research Program that will be carried out by our groups. As I mentioned, I must leave this hearing in a few minutes to return to a meeting at which we will continue our review. Specifically, we will be hearing from NASA and the other Federal agencies about their responses to the recommendations reached last summer. It is unfortunate that delays caused by weather and government shutdowns resulted in a conflict with this hearing.

As we embarked on this study, we were acutely conscious of its context: the complexity and challenge of the underlying science, changing societal expectations with regard to large scientific programs, downward budget pressures, concerns over ensuring the program's political neutrality, and increased awareness by the scientific community that it had to exercise greater leadership in program governance.

For the purposes of this testimony, I have grouped the Committee's recommendations into three broad categories: a discussion of scientific progress, programs and priorities; a review of program management and integration issues; and a set of recommendations focused specifically on NASA's MTPE/EOS program. In addition to summarizing the most critical findings and recommendations in the 1995 study report, I have also attempted to address some of the specific issues identified in the charter for this hearing.

SCIENTIFIC PROGRESS, PROGRAMS AND PRIORITIES

First, we concluded that the overall quality of the program's science is high. The program has already yielded many landmark scientific achievements. The researchers associated with the USGCRP in universities, industry, government laboratories, and among our international partners are smart and highly dedicated. Most importantly, they go where science, not politics, leads. We reaffirmed that assessing the state of the Earth's environment and learning to predict its evolution are important, challenging, and tractable scientific goals. We urged the aggressive pursuit of these goals. We concluded that, "Science is the fundamental basis for the USGCRP and its component projects, and that fundamental basis is scientifically sound."

Recognizing the need to focus limited resources on the highest priority issues, the Committee specifically identified four mature areas of USGCRP research that are of great scientific and practical importance. Enhanced, focused efforts in these areas promise tangible near-term

benefits to society, and strengthened scientific understanding of global environmental conditions:

1. Seasonal to interannual climate prediction: Improve prediction skills related to El Ni%o and expand predictive skills beyond the tropics to the extent possible; enhance understanding of land-atmosphere interactions; and establish an international research prototype prediction capability.

2. Atmospheric chemistry: Enhance research and scientific assessment on tropospheric chemistry, including tropospheric ozone and its precursors; characterize global distributions of aerosols; monitor biogenic gases especially over continental areas; and continue monitoring and scientific assessment of ozone in the stratosphere, including links to climate.

3. Ecosystems: Improve documentation, assessment, and understanding of the global carbon cycle; investigate the relationships among vegetation, climate, and land use; study the role of managed and natural ecosystems in the exchange of water, carbon dioxide, and biogenic gases; and provide for the inclusion of surface atmosphere processes and ecosystem dynamics in integrative models and scientific assessments.

4. Decadal to centennial climate: Document, investigate, and assess changes in forcing factors that influence climate; incorporate ocean, land, atmosphere, and ice processes and feedbacks in coupled models; document change through long-term monitoring and assessment

of primary climate system characteristics; and investigate economic, technological, and demographic trends that affect the ability of natural and human systems to respond to climate variability and change.

The Committee's report and supporting appendices provide further details on the scientific progress to date, and priorities within, each of these four areas. It also addresses some of the crosscutting programmatic issues that support them all, such as observing systems and data management. Successful implementation of a U.S. Global Change Research Program focused on these high-priority issues will require significant interdisciplinary and interagency linkages which, in turn, require a high level of programmatic integration.

PROGRAM MANAGEMENT AND INTEGRATION ISSUES

Our review concluded that the US Global Change Research Program should be implemented as an integrated program of observations, process research, modeling, prediction, information management, and assessment that incorporates the unique assets and capabilities of the participating agencies and their extramural research programs. This requires the active participation of the scientific community, the Congress, the federal agencies, and the Executive Office of the President in a cooperative process. We believe that the potential implications for society in all four science areas lend urgency to pursuing the program at an aggressive pace. This pace can only be achieved if these issues are addressed.

We noted that the USGCRP must rapidly adopt advances in technology to improve performance and lower cost. Moreover, the USGCRP management must ensure that the program is open and accessible to broad participation by the government, academic, and private sectors to achieve these cost reductions while maintaining and improving quality and performance. Further, we urged that the program utilize systems and data products from related monitoring systems such as the ground-based and satellite observations supporting operational weather forecasting and other commercial systems, wherever possible.

MTPE/EOS ISSUES

The USGCRP requires an integrated observational strategy in which the choice of tools and approaches is driven by scientific needs and reflects an appropriate balance between in situ and remotely-sensed observations to produce integrated information products for use by the research community and decision makers in the public an private sectors.

EOS was initiated as the centerpiece of the USGCRP observational program in response to scientific needs. A continuing series of reviews has resulted in improving the program but the present study found it essential that further improvements be made.

Our recommendations were:

Maintain a science-driven approach to observational and information management technology.

Implement the first group of Mission to Planet Earth (MTPE)/Earth Observing System (EOS) components: Landsat-7, AM-1, PM-1, Chemistry-1 (Chem-1), and the Tropical Rainfall Measuring Mission (TRMM).

Enhance in situ observation programs, process studies, and large-scale modeling activities.

Develop advanced technologies to reduce the costs of continuing essential observations.

Focus the tropospheric component of Chem-1 on the global distribution of ozone and its precursors.

Implement a future framework for MTPE that incorporates advanced instrumentation and vehicle technologies, such as small satellites and remotely piloted vehicles (RPVs), as an integral component of the program, including planning for EOS missions beyond the first group of platforms. Incorporate scientific needs into interagency and international planning for satellite convergence.

Streamline current the EOSDIS plans for data downlink and Level-0 processing.

Reconfigure EOSDIS to transfer responsibility for product generation, publication, and user services to a competitively selected federation of partners in government, academia, and the private sector.

The proposed re-balancing of EOS appears to offer the potential for significant economies -- e.g., by focusing and simplifying the tropospheric component of the Chem-1 mission on ozone and its precursors, by streamlining the data downlink and initial processing of EOSDIS, and by employing a federation of partners in EOSDIS for product generation. The latter two steps potentially contribute the greatest saving. The current distributed client-server design of EOSDIS is responsive to community needs, and its engineering development, and should continue. However, the EOSDIS management and operations concept should be redefined to involve the broad user community effectively.

We went on to argue that it will be necessary to redirect some of the resources that might be released by these measures towards

(1) expanding in situ observations, process studies, and large-scale modeling;

(2) developing advanced technology to reduce costs of second-and third-generation missions, and to open new scientific opportunities.

With integrated, science-driven, and balanced scientific and observational elements, the USGCRP and NASA's MTPE/EOS can continue to contribute importantly to ensuring our national welfare in a changing global environment.

OTHER ISSUES

Mr. Chairman, if you will permit me, I would like to speak for a few minutes for myself, and not for the NRC.

It is clear to all of us that severe budgetary pressures are causing you and other officials to seek disposable funds from cuts in many programs. When we left the workshop last summer, we believed that the recommendations we made would permit such shifts in resources, and improve the program in the bargain. Your charter for this hearing has identified some of the ways in which funds for reinvestment might be garnered : cut back on nearer term launches and sensors (PM-1, etc.), cut back on EOSDIS, utilize new and cheaper technology, and employ alternative data sources.

I am a member of the MEDEA group which is examining in detail the use of data collected by the military and intelligence agencies for environmental applications. I believe I can attest to the fact that the government has examined the issue you raised about joint use. While promising in certain respects, this approach will only afford minimal savings. In an appropriate setting I am sure that this can be discussed in greater detail.

Reduced costs through revolutionary spacecraft technologies are highly likely in the future. Many experts who have examined this area believe this to be true. Unfortunately, however, at the current place in the development cycle we cannot yet rely on such savings.

You are again correct in pointing out the potential of an emerging remote sensing industry. I have been briefed, within appropriate proprietary considerations, on the license applications that NOAA has received to date. They include 1 meter and 3 meter visual systems and similar resolutions for the infrared and near infrared systems. Again, this offers some data but does not cover all the types needed for the global change mission.

On the point you raised relative to relying on international cooperation, I think we all agree that this should be pursued much more vigorously than it has been and that it is likely to pay off. It should be pointed out that many elements of the USGCRP and NASA's MTPE are being implemented with international linkages right now.

First, the many projects of the World Climate Research Program and the International Geosphere-Biosphere Program are integral parts of our scientific strategy. For example, the TOGA program that yielded impressive new capabilities in seasonal to interannual climate prediction was carried out by a consortium of some twenty nations.

In the case of MTPE and EOS specifically, several important elements testify to the opportunities afforded by international collaboration:

- The Japanese ASTER instrument and ADEOS mission

- The joint US-Japanese TRMM mission

- Russian contributions to SAGE III in spacecraft, launch, and operations

- Canadian MOPITT instrumentation and interdisciplinary science investigations

Finally, let me state again my conviction that the USGCRP and NASA's MTPE and EOS are fundamentally sound scientific programs of immense importance to the future welfare of our country and our world. I continue to believe that through sound, balanced, and well-integrated management, including the imaginative use of advanced technology and both domestic and international partnerships, the resources can be found to continue them successfully and within our means.

I thank you for your attention, and for the opportunity to present the conclusions of the NRC groups I represent, as well as my own views.

A Review of the U.S. Global Change Research Program and NASA's Mission to Planet Earth/ Earth Observing System

Committee on Global Change Research
Board on Sustainable Development
Policy Division
National Research Council

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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Preface

This report reflects the results of a ten-day workshop convened at the Scripps Institution of Oceanography July 19-28, 1995. The workshop was convened as the first phase of a two-part review of the U.S. Global Change Research Program (USGCRP), which is being conducted in response to

1. the long-standing commitment of the National Research Council (NRC) to providing scientific guidance and periodic review of the USGCRP and its component programs and plans; and

2. requests from congressional leaders in both the House and the Senate, endorsed by the interagency Subcommittee on Global Change Research, for a timely review of the USGCRP with an early specific focus on the NASA Mission to Planet Earth (MTPE) and Earth Observing System (EOS) programs in the light of budgetary pressures.

Responsibility for the review of the USGCRP was assigned to the Board on Sustainable Development (BSD) and its Committee on Global Change Research (CGCR). The July workshop was designed to accomplish the first phase of the review -- to conduct an initial assessment of the scientific progress to date in the USGCRP -- and, in the context of that scientific assessment, review the specific role of NASA's Mission to Planet Earth/Earth Observing System (MTPE/EOS) program.

As phase one of the review, the workshop was organized to provide

- a review of the scientific foundations and progress to date in the US. Global Change Research Program and an assessment of the implications of new scientific insights for future USGCRP and MTPE/EOS activities;

- a review of the role of NASA's MTPE/EOS program in the USGCRP observational strategy;

- a review of the EOS Data and Information System (EOSDIS) as a component of USGCRP data management activities; and

- an assessment of whether recent developments in the following areas lead to a need to readjust MTPE/EOS plans. Specific consideration was given to

  - proposed convergence of U.S. environmental satellite systems and programs,
  - evolving international plans for Earth observation systems,
  - advances in technology, and
  - potential expansion of the role of the private sector.

While we believe that this initial emphasis on MTPE/EOS was appropriate in light of the need to be responsive to specific congressional interests, we recognize that, as a result, the July workshop could not adequately address the full spectrum of issues important to a review of the U.S. Global Change Research Program. For example, in consultation with the federal agencies participating in the USGCRP, the initial scientific assessment of the program was organized around four key scientific areas: (1) seasonal to interannual climate prediction, (2) atmospheric chemistry; (3) ecosystems; and (4) decadal to centennial climate change. Taken together, these four science areas reflect the continuing evolution of global change research into higher levels of intellectual and programmatic integration. Although these four areas represent the appropriate principal scientific foci for the USGCRP, the program's progress must also be evaluated in the individual Earth science disciplines that provide the foundation for an increasingly integrated view of the Earth system. Some of these disciplinary areas, such as climate and hydrological systems, biogeochemical cycles, and ecological systems and dynamics, received focused attention at the workshop. A detailed look at others, such as Earth system history, solar influences, and solid Earth processes, was deferred until the second phase of the review.

Research into the human dimensions of global change is a special case that deserves specific mention here. The workshop was designed with an explicit understanding that an effective program of research in all four of the principal science areas requires the integration of physical, natural, and social and economic sciences. Unfortunately, representation from the social science and economics research communities was limited during the workshop. As a result, we plan to include an explicit focus on the human dimensions of global change during the second phase of the review.

The present report summarizes the findings and recommendations developed by the Committee on Global Change Research on the basis of the presentations, background materials, working group deliberations, and plenary discussions of the workshop. A majority of the members of the committee participated in the La Jolla workshop. The report was subsequently reviewed in detail by the full membership of the CGCR, and the final text reflects extensive com-

ments and modifications by the committee members. The committee believes these conclusions to be representative of the consensus of the workshop; however, their specific content is the responsibility of the committee alone.

In addition, we have appended summaries prepared by the six working groups convened in the course of the workshop (Appendixes A-F). These documents were written by the designated working group chairs and reflect their sense of the views of working group participants, further illuminated by extensive plenary discussions in the course of the workshop. These documents provide a window into the information, analysis, and discussion drawn upon by the committee in formulating its conclusions. The chairs of the six working groups are also preparing a set of more complete interim working documents that describe their deliberations in more detail and will be used as critical input to the second phase of the comprehensive review of the USGCRP.

The July workshop constituted the first step in a broader review of the USGCRP as a whole that will be concluded at a meeting of the Committee on Global Change Research in the late fall or early winter of 1995. In light of the issues raised at the workshop, we anticipate that this meeting will provide an opportunity to address a number of remaining issues, including

- completion of a review of the USGCRP scientific accomplishments and priorities, including a more detailed look at disciplinary areas not fully addressed during the workshop;

- an in-depth look at the roles and responsibilities of the participating agencies and further discussion of interagency program management issues;

- an evaluation of USGCRP programs and plans in the areas of integrated observations, information management (including EOSDIS), process studies, modeling and prediction, and assessment;

- further discussion of the development of an integrated observational strategy for the USGCRP, including analysis of the opportunities and requirements associated with the planned convergence of Department of Defense (DoD) and civilian meteorological satellite programs;

- a review of USGCRP contributions to international global change research programs including the World Climate Research Program, the International Geosphere-Biosphere Program, and the Human Dimensions of Global Change Program; and

- the practical applications of the results of USGCRP research and an assessment of the program's effectiveness in meeting the needs of decision makers in the public and private sectors.

The Committee on Global Change Research will then prepare a comprehensive review of the U.S. Global Change Research Program for release early in 1996.

The workshop brought together a broadly constituted group including members of the Committee on Global Change Research and the Board on Sustainable Development; chairs or representatives of other relevant NRC units concerned with elements of the USGCRP; leaders of the major international global change research programs; and other invited scientists and technologists from academia and industry selected for their expertise and experience in relevant technical areas. In order to ensure the required level of expertise, scientists currently active in the USGCRP and supported by the agencies participating in the program were invited to take part. We also want to point out that some members of the Committee on Global Change Research also receive funding from USGCRP agencies. However, to foster a balanced and objective review, the workshop also included experts outside the USGCRP research community, as well as individuals who have been critical of the USGCRP and of NASA's MTPE/EOS program in the past. The workshop also benefited from the presence of representatives of USGCRP agencies (Appendix G). These representatives were invited to make formal presentations and to serve as liaisons to provide workshop participants with the background information and programmatic details required to support their deliberations. We appreciate greatly their contributions of time, expertise, and experience over the week and a half of the workshop.

As workshop co-chairs, we worked closely with the Subcommittee on Global Change Research of the interagency Committee on Environment and Natural Resources in planning the workshop, to develop appropriate background information, and to identify the appropriate level of agency participation. We are very grateful to the many individual federal officials associated with these organizations for their contributions to this effort.

Finally, we wish to express our appreciation to the NRC staff--John Perry and Claudette Baylor-Fleming of the Board on Sustainable Development and volunteer staff members from other NRC units--Frank Eden, Mary Hope Katsouros, and Anne Linn,who worked long hours to bring this project to fruition. In addition, we are grateful for the contributions provided by Eileen Shea of the Center for the Application of Research on the Environment (CARE), who served as study director for this first phase of the USGCRP review and for the La Jolla workshop. We are sure that the many participants share our appreciation of the staff of the Scripps Institution of Oceanography for their unstinting and uniformly effective support of this demanding enterprise.

Berrien Moore III, *Chairman*
Committee on Global Change Research

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Board on Sustainable Development

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Executive Summary

Assessing accurately the current state of the global environment and increasing our predictive capabilities to aid in anticipating how this environment may evolve are enduring challenges to science. The U.S. Global Change Research Program (USGCRP) seeks to advance scientific understanding of the global environment, assist federal agencies in their missions, and provide reliable information for decision making. The scientific and societal motivations of the program remain compelling, and it should be aggressively pursued.

Future development of the USGCRP should be based on a set of guiding principles:

- Science is the fundamental basis for the USGCRP and its component projects, and that fundamental basis is scientifically sound.

- The **balance** of activities within the program must reflect evolving **scientific priorities.**

- In addition to observational systems and data streams implemented as explicit components of the usgcrp, the program should make use of **existing observational systems and data products** implemented in support of related environmental monitoring and earth science programs (e.g., the ground-based and satellite observations that support operational weather forecasting).

- The USGCRP must utilize **advancing technology** in addressing these evolving priorities.

- An **open and accessible** program will encourage broad participation by the government, academic, and private sectors.

- Success in attacking the long-term scientific challenges of the USGCRP requires an **adequate and stable level of funding** that promotes management efficiencies and encourages rational resource allocation.

- Successful implementation of the USGCRP and the realization of its benefits require **informed leadership and collaboration** among the government, academic, and private sectors.

The USGCRP, furthermore, must be implemented as an **integrated** program of observations, process research, modeling, prediction, information management, and assessment. In order to achieve this, **enhanced collaboration and cooperation** are required among the scientific community, the Congress, federal agencies, and the Executive Office of the President to ensure that all elements of the program are considered in the context of the integrated program as a whole.

The program should focus on priority issues in four mature areas of Earth system science that are of great scientific and practical importance. Each area will require the contribution of a variety of traditional Earth science disciplines:

1. **Seasonal to interannual climate prediction:** Improve prediction skills related to El Niño and expand predictive skills beyond the tropics to the extent possible; enhance understanding of land-atmosphere interactions; and establish an international research prototype prediction capability to garner multinational support and to provide benefits to participating countries where usable predictive skill has been demonstrated.

2. **Atmospheric chemistry:** Enhance research and scientific assessment on tropospheric chemistry, including tropospheric ozone and its precursors; characterize global distributions of aerosols; monitor biogenic gases especially over continental areas; and continue monitoring and scientific assessment of ozone in the stratosphere, including links to climate.

3. **Ecosystems:** Improve documentation, assessment, and understanding of the global carbon cycle; investigate the relationships among vegetation, climate, and land use; study the role of managed and natural ecosystems in the exchange of water, carbon dioxide, and biogenic gases; and provide for the inclusion of surface atmosphere processes and ecosystem dynamics in integrative models and scientific assessments.

4. **Decadal to centennial climate:** document, investigate, and assess changes in forcing factors that influence climate; incorporate ocean, land, atmosphere, and ice processes and feedbacks in coupled models; document change through long-term monitoring and assessment of primary climate system characteristics; and investigate economic, technological, and demographic trends that affect the ability of natural and human systems to respond to climate variability and change.

These areas are at different stages of maturity. They have different levels of access to existing remotely sensed data, and each area can make unique contributions to the study of global change. In all these areas, linkages among the physical, natural, and social sciences should be enhanced, and effective U.S. participation in international global change research programs should be encouraged.

Observations of the Earth system play a key role in the USGCRP, and the program requires an integrated observational strategy based on scientific needs, the development and implementation of observing systems appropriate to those needs, scientific guidance, and the application of technological capabilities as appropriate. NASA's Earth Observing System (EOS) should reflect that integrated strategy.

Based on a series of reviews, the program has evolved from its original plans to a reshaped program that is more responsive to the science, more resilient, and more open to the introduction of new technology. There has been a shift from a fixed series of large-vehicle missions to a mixed fleet exploiting small to medium class spacecraft. However, any further structural changes to the near-term EOS missions would cause severe program dislocations. Further budgetary reductions or imposed constraints on technical options could require the elimination of key sensors, slips in schedule, loss of data continuity, and the elimination of advanced technology development that could enhance future research and lower costs.

However, continued evolution is essential. NASA, in concert with the USGCRP community, should consider carefully the observational strategy appropriate for the post-2004 era to ensure that the EOS strategy remains technologically current and scientifically relevant. In the meantime, as a result of technological advances, scientific insights, and programmatic evolution, NASA should move to rebalance the EOS program across space assets, in situ measurements, modeling and process studies, and the data and information management system through a set of feasible and cost-effective actions.

- Maintain a science-driven approach to observational and information management technology.

- Implement the first group of Mission to Planet Earth (MTPE)/Earth Observing System (EOS) components: Landsat-7, AM-1, PM-1, Chemistry-1 (Chem-1), and the Tropical Rainfall Measuring Mission (TRMM).

- Enhance in situ observation programs, process studies, and large-scale modeling activities.

- Develop advanced technologies to reduce the costs of continuing essential observations.

- Focus the tropospheric component of Chem-1 on the global distribution of ozone and its precursors.

- Implement a future framework for MTPE that incorporates advanced instrumentation and vehicle technologies, such as small satellites and remotely piloted vehicles (RPVs), as an integral component of the program, including planning for EOS missions beyond the first group of platforms. Incorporate scientific needs into interagency and international planning for satellite convergence.

- Streamline current the EOSDIS plans for data downlink and Level-0 processing.

- Reconfigure EOSDIS to transfer responsibility for product generation, publication, and user services to a competitively selected federation of partners in government, academia, and the private sector.

The proposed rebalancing of the programs would offer the potential for significant economies, (e.g., by focusing and simplifying the tropospheric component of the Chem-1 mission on ozone and its precursors, by streamlining the data downlink and initial processing of EOSDIS, and by employing a federation of partners in EOSDIS for product generation). The latter two potentially contribute the greatest savings, and the last offers significant new opportunities to research and private sector communities. To ensure scientific success, however, it will be necessary to direct the resources toward (1) expanding in situ observations, process studies, and large-scale modeling; and (2) developing advanced technology to reduce the costs of second- and third-generation missions and to open new scientific opportunities. With integrated, science-driven, and balanced scientific and observational elements, the USGCRP and NASA's MTPE/EOS program can continue to contribute importantly to ensuring our national welfare in a changing global environment.

Introduction

The U.S. Global Change Research Program and its international counterparts were begun to enhance understanding of the global environment and to predict its future evolution. Such collaborative work has long been a hallmark of the Earth and life sciences, in which investigations characteristically transcend the boundaries of classical scientific disciplines and individual nations. Thus, a long history of increasingly ambitious and increasingly integrated scientific programs may be traced, from the polar programs of the late nineteenth century through the International Geophysical Year of 1958 to the Global Atmospheric Research Program, the International Decade of Ocean Exploration, and the International Biology Program of the 1970s.

By the 1980s, a growing body of research, coupled with new views of the Earth from space, reinforced science's vision of our planet as a tightly interconnected and constantly changing system. Public awareness of the links between the current and future state of the global environment and human activities increased during this same period. In combination, scientific insights, technological opportunities, and societal concerns led to proposals for ambitious new scientific programs to advance our understanding of the Earth system.

For these reasons, President Reagan in January of 1989 announced the United States Global Change Research Program (USGCRP) as a presidential initiative for fiscal year 1990 and the federal government's effort to establish the scientific basis for national and international assessments of changes, both natural and human induced, in the Earth system. President Bush reaffirmed the initiative, and congress codified the program through passage of the Global Change Research Act of 1990. President Clinton has continued to support the USGCRP as a priority in the national science and technology agenda. Parallel international programs already existed or were created dealing with the climate system, geosphere-biosphere issues, and interactions between the environment and human activity.

The USGCRP has grown programmatically from diverse roots in existing programs and planned activities within several federal agencies and reflects the evolution of closely related international programs such as the World Climate Research Program (WCRP), the International Geosphere-Biosphere Program (IGBP), and the Human Dimensions of Global Environmental Change Program (HDP).

In the early 1980s, the National Aeronautics and Space Administration (NASA) advanced a comprehensive new program: Mission to Planet Earth (MTPE). The centerpiece of the new program was an ambitious series of new satellites called the Earth Observing System (EOS). The satellite and the research and analysis programs of NASA's MTPE are key contributions to the USGCRP. Similarly, the early 1980s saw the emergence of the National Science Foundation's Global Geosciences initiative, and in 1989 the National Oceanic and Atmospheric Administration (NOAA) also began a Climate and Global Change Program focusing on related scientific objectives. With the formal initiation of the USGCRP as a presidential initiative in fiscal year 1990, contributions from the Department of Interior's U.S. Geological Survey were incorporated into the program.

Today, the USGCRP reflects the programmatic contributions of 11 federal agencies. Under the auspices of the National Science and Technology Council, the Subcommittee on Global Change Research of the Committee on Environment and Natural Resources provides the principal federal mechanism for integrating these individual agency efforts into a coordinated program. From the perspective of the participating agencies, the USGCRP fulfills three related objectives:

1. advancing scientific understanding of the global environment;
2. meeting agency-specific missions and responsibilities; and
3. providing reliable scientific information to support national and international decision making.

In the decade since the planning for the USGCRP began, much has been learned regarding the forces producing global change and the complexity of the connections between those forces and responses in the Earth system. We can point to many achievements, some scientific and some having significant economic value. A great deal of extremely high-quality science that is recognized worldwide for its excellence and leadership has resulted from the USGCRP. We have gained a greater appreciation of the need to link physical and natural scientific studies with those addressing the social sciences and economics. Thus, although the motivation for the USGCRP retains its original force and the scientific foundations remain strong, our experience suggests the need for improved management and broader participation and perspectives.

GUIDING PRINCIPLES

As the foundation for the recommendations that follow in this report, the Committee on Global Change Research:

- **confirms** that there have been many landmark scientific achievements of the U.S. Global Change Research Program;

- **reaffirms** that assessing the state of the Earth's environment and developing an understanding sufficient to predict how the planet's environment may evolve, including changes in the Earth's climate system, are important, tractable, and challenging scientific goals; and

- **urges** the aggressive pursuit of these goals.

Building on this foundation, the Committee on Global Change Research has enunciated the following set of **fundamental guiding principles** that should guide the development and implementation of the U.S. Global Change Research Program in the future:

- Science is the fundamental basis for the USGCRP and its component projects, and that fundamental basis is scientifically sound.

- The **balance** of activities within the program must reflect evolving scientific priorities.

- In addition to observational systems implemented as explicit components of the USGCRP, the program should make use of **existing observational systems and data products** implemented in support of related environmental monitoring and Earth science programs (e.g., the ground-based and satellite observations which support operational weather forecasting).

- The USGCRP must utilize **advancing technology** in addressing these evolving priorities.

- An **open and accessible program** will encourage broad participation by the government, academic, and private sectors.

- Success in attacking the long-term scientific challenges of the USGCRP requires an **adequate and stable level of funding** that promotes management efficiencies, encourages rational resource allocation, and allows examination of key scientific questions requiring a long-term approach.

- Successful implementation of the USGCRP and realization of its benefits require **informed leadership and collaboration** among the government, academic, and private sectors.

SCIENTIFIC DIRECTIONS

The activities of the U.S. Global Change Research Program are aimed at well-focused scientific issues of global change. These issues reflect the continuing evolution of global change research toward increasing levels of intellectual and programmatic integration and represent the appropriate principal foci for the USGCRP. The questions identified within each of these four scientific areas are intended to illustrate the lines of scientific inquiry that characterize the program's efforts. In the areas of seasonal to interannual climate and atmospheric chemistry, these questions reflect a highly refined set of specific priorities characteristic of the level of scientific and programmatic maturity achieved by USGCRP programs in those areas. The more general questions associated with climate change on the time scale of decades and with large-scale ecosystem change are characteristic of the somewhat more exploratory nature of research in these fields.

Seasonal to Interannual Climate Fluctuations

How does the El Niño/Southern Oscillation (ENSO) cycle in the tropical Pacific contribute to climate anomalies and related extreme events such as droughts, floods, and severe storms, and what other processes are involved? What are the controlling processes relevant to climate on seasonal to interannual time scales and regional to global spatial scales? Can we develop predictive models that include these processes? How can we predict seasonal to interannual climate fluctuations and associated extreme events, and how do we simulate the potential economic impacts on agricultural, water resource, and other socioeconomic systems?

Changes in the Chemistry of the Atmosphere

What are the trends and patterns of change in ozone concentrations in the stratosphere and upper troposphere, and the related trends and patterns of ultraviolet radiation at the Earth's surface and climate perturbations? What are the trends of tropospheric ozone, aerosols, and pollutants in the lower atmosphere? Can we model the physical and chemical processes in the atmosphere to permit prediction of changes in ozone, aerosols, pollutants, and related climate effects? Can we assess the implications of changing concentrations of ozone and other chemical species on human health and natural ecosystems?

Changes in Terrestrial and Marine Ecosystems

What are the trends and the geographic and temporal patterns of change in global land cover? What are the processes, both natural and human induced, that lead to changes in land cover, land use, and marine productivity, including such processes as deforestation, desertification, and loss of global resources, including biological diversity and productivity? How do managed and natural ecosystems interact with the atmosphere in the exchange of energy, water, carbon dioxide (CO_2) and trace gases, and how do those exchanges affect global and regional climates and water resources? What are the processes that control the exchange of biogenic trace gases between terrestrial ecosystems and the atmosphere? What is the distribution of sources and sinks for CO_2 and how is it changing? What processes govern the ocean's uptake of atmospheric carbon dioxide? What governs the variability of phytoplankton communities that form the base of the oceanic food chain? What are the links with higher species--fish, invertebrates, and mammals?

Changes in Climate over the Next Few Decades

What are the trends and patterns of change in the Earth's climate system, including the atmosphere, oceans, glaciers, sea ice, and the biosphere? How have these patterns varied in the past? What is the nature of the processes relevant to the dynamics of climate, including both internal factors such as water vapor, clouds, and heat transfer by the atmosphere and oceans, and external factors such as solar variability and volcanic activity? Can we develop predictive models of regional to global climate change over time scales from a decade to a century? What is the vulnerability of Earth systems, including economies, human health, and ecological systems, to climate fluctuations and changes on these time scales?

PROGRAM MANAGEMENT

The experience of the past decade or so has provided valuable insights into the management of large-scale Earth science projects. Those elements of the USGCRP that have worked well (e.g., the WCRP Tropical Ocean-Global Atmosphere (TOGA) Program and research on stratospheric ozone) have been focused on clearly defined Earth system problems and have been characterized by close collaboration within and among the national and international scientific communities and federal funding agencies on both development and the implementation. When this collaborative approach works well, the scientific community and the responsible parties in the federal government (both executive and legislative branches) share a scientific vision and a commitment to the programmatic discipline necessary to implement that vision:

- Scientific plans are developed with broad community participation.
- Federal funding agencies commit to a resource allocation strategy that adheres to those plans.
- Individual agency capabilities and assets are brought to bear on the problem, and program implementation decisions are made on the basis of scientific merit and relevance and are independent of agency boundaries.
- Responsibility for program direction and balance is shared among leaders in both government and the scientific community.
- National programs reflect clear ties to the related activities of our international partners and constitute formal U.S. contributions to established international global change research programs such as the WCRP, IGBP, and the HDP.
- Clear procedures for scientific review and guidance are established.
- Program participants in and out of government share responsibility for ensuring that research results are made available both to their scientific colleagues and to potential users.

The specific findings and recommendations that follow provide guidance toward taking the next steps in the evolution of the USGCRP and NASA's MTPE/EOS program.

Findings and Recommendations

PROGRAM-WIDE FINDINGS AND RECOMMENDATIONS

The past decade of research within the U.S. Global Change Research Program (USGCRP) has produced remarkable improvements in our understanding of Earth system behavior and its interaction with human activities. We have gained valuable insights into the characteristics of a successful global change research program. These insights lead the Committee on Global Change Research to the following programmatic recommendations for the USGCRP.

Recommendations

The USGCRP must

- maintain a **balanced** program of space- and ground-based observations, laboratory- and field-based process research, information management, modeling, prediction, and assessment activities in which the interaction among these program elements is as important as the success of each;

- identify clearly the **essential** elements of the program, while recognizing the contributions of related programs and activities;

- ensure the development and successful implementation of **integrated** scientific plans across agency boundaries;

- maintain strong and effective linkages with **international** global change research and observation programs; and

- obtain timely **guidance** from the scientific community on priorities, program balance, and direction.

The USGCRP is making an effort in each of these dimensions; however, the committee is concerned that the current efforts and their effectiveness may not be adequate to the task.

The USGCRP must encompass numerous scientific disciplines and areas of activity. Critical aspects of the program cross both discipline and agency boundaries. Thus, interdisciplinary and interagency linkages are central to successful implementation of the program. The needed **programmatic integration** is not currently being achieved adequately. Specifically, important elements of the USGCRP may be lost due to agency boundaries and individual agency funding difficulties.

- The USGCRP should be implemented as an **integrated program** of observations, process research, modeling, prediction, information management, and assessment that incorporates the unique assets and capabilities of the participating agencies and their extramural research programs. The necessary program integration and coordination must be achieved through **enhanced collaboration and cooperation among** the scientific community, the Congress, federal agencies, and the Executive Office of the President in the program's planning, implementation, and funding.

To that end,

- The **scientific community**, through its established advisory mechanisms, should

  - provide more timely **scientific guidance** on program priorities, balance and direction;
  - ensure **broader and more balanced** expert representation in advisory processes;
  - promote more effectively U.S. contributions to **international** global change research programs; and
  - conduct periodic **external reviews** to assess scientific progress and evaluate programmatic integration and performance.

- The **Congress** should

  - ensure that program authorizations and resource allocations to individual agencies are consistent with the implementation of an **integrated** program. (This is not currently being done); and
  - provide a mechanism for **bipartisan, bicameral oversight** of the effectiveness of the program in meeting the information needs of the nation.

- The **Executive Office of the President and federal agencies** should

  - implement USGCRP projects on an **interagency** basis using joint program announcements and pooled resources;
  - establish multiagency programs to **integrate and jointly manage** the crosscutting elements of the program such as training and education; and
  - provide a structure for **effective interagency decisions** on programmatic content and resource allocation including, where appropriate, designation of a lead agency or an interagency program office. The current approach to interagency coordination is not adequate, and its shortcoming are particularly damaging in these difficult budgetary times. The committee believes that the current interagency coordination structure lacks the level of programmatic discipline and agency accountability required to implement the USGCRP as a fully integrated interagency program.

The scientific problems of global change are complex and often cross the boundaries between traditional scientific disciplines. Young scientists, whose training is still relatively narrow, may thus have difficulty obtaining support, and their contributions may consequently be limited. The multidisciplinary character of the research, coupled with the disciplinary structure of traditional funding mechanisms, may hinder the emergence and recognition of capable leaders in science and government.

- The USGCRP and its component programs should encourage the recruiting and support of young scientists, particularly those capable of addressing inherently interdisciplinary Earth science problems.

- Professional societies, universities, and funding agencies should take new steps to ensure that scientists and program managers are recognized for unique contributions to the development and implementation of global change research.

SCIENTIFIC DOMAINS

The Committee on Global Change Research believes that four areas of Earth system science currently addressed by the USGCRP have reached a level of maturity at which enhanced, focused efforts promise tangible near-term benefits to society, including providing a sound, scientifically based assessment of the current state of the Earth's environment, while strengthening the scientific base for prediction of future global environmental conditions:

Seasonal to Interannual Climate Prediction

The concept of "end-to-end prediction" (i.e., the use of fundamental science to develop sound predictive schemes that yield products explicitly useful to human activities) motivates and guides all the components of this part of the program and sets its priorities and balance of elements, which include the following:

- development of coupled atmosphere-ocean-land models;
- combination of both in situ and satellite observations to initialize the models and an efficient data system to support this combination;
- investigation of poorly understood processes such as land-atmosphere interactions and atmosphere-ocean-land interactions outside the tropics; and
- research to support the application and evaluation of these forecasts.

Recommendations

- Direct research toward
  - improving the skill of **predictions of El Niño** for use in the tropical Pacific; and
  - **enhancing predictive skills in areas beyond the tropics** to the extent possible for future applications in sectors such as agriculture and water resource management.
- Enhance understanding of **land-atmosphere interactions** with
  - an **initial emphasis on the Mississippi basin**, to determine the predictability of regional precipitation and hydrologic water budget with future applications for agriculture and local economies; and
  - a **second focus on the Amazon basin** to further our understanding of energy and water exchange over the tropical land masses.
- Establish an **international research prototype prediction capability**, including a focused facility (the proposed International Research Institute) and a supporting research program in order to
  - accelerate the application of demonstrated predictive capabilities;

-- secure multinational support for global-scale observing systems and international research programs; and
-- focus research to extend predictive capabilities and applications.

Atmospheric Chemistry

The chemical composition of the atmosphere has been changing rapidly over the last several decades. Global change research has been successful in developing a scientific understanding of several of these changes such as stratospheric ozone depletion. However, the assessment and understanding of other problems such as tropospheric ozone and aerosols and their roles in climate and chemical processes remain largely inadequate.

Recommendations

- Enhance USGCRP research and its relationship to assessment in **tropospheric chemistry**.
- Improve estimates of **regional and national trends** in anthropogenic **trace gas emissions**.
- Enhance the focus on **tropospheric ozone** and its precursors through an **optimized combination** of space-based and in situ observations, laboratory studies, and modeling.
- Characterize the global distribution and processes associated with tropospheric **aerosols**.
- Extend to continental regions the current coastal and island networks monitoring **biogenic gases**.
- Conduct uninterrupted, careful monitoring and scientific assessment of **total ozone and other ozone trends in the lower stratosphere**, and evaluate their **links to climate change**.

Ecosystems

Prediction of future global environmental changes requires a scientific assessment of the current condition of terrestrial and marine ecosystems and an understanding of large-scale

terrestrial and marine ecological processes. Integrative Earth system models are important tools for assimilating and ordering this ecological information.

Recommendations

- Extend, both spatially and temporally, observing programs and process studies to document changes of the global carbon cycle in the atmosphere, in the ocean, and in the terrestrial system.

- Implement promptly national and international plans for scientific investigations of large-scale trends, patterns, and relationships among vegetation, climate, and human land use to document the interaction between natural and human systems for communication to resource managers.

- Study the interactions between both managed and natural ecosystems and the atmosphere in the exchange of energy, water, carbon dioxide, and trace gases and the effects of these exchanges on global and regional climates and water resources.

- Develop and validate ecosystem components and surface-atmosphere processes in integrative climate models.

Decadal to Centennial Climate

Anthropogenic forcing of climate change is an important problem, and significant additional scientific progress can be achieved that will serve society well. The problem should be studied in the context of natural climate variability over time scales of decades, centuries, and even millennia, and the interrelated trends in economies, technology, and demography.

Recommendations

- Investigate and assess changes in all the major forcing factors that influence climate variability and change and their interactions.

- Through models that couple the components of the Earth system--including the ocean, atmosphere, land, and ice--explore the major feedback processes, and thereby reduce the uncertainties in projecting future climate and its impact on human societies.

- Document the primary characteristics of the climate system by means of consistent long-term observations.

- Investigate critical **economic, technological, and demographic trends that** are affecting the ability of natural and human systems to cope with climate variability and change, including changes in urban infrastructure, farming technologies, trade, and water use and efficiency that can increase vulnerability or resilience to global change.

CROSSCUTTING ISSUES

The Committee on Global Change Research believes that a number of issues regarding the programmatic framework and supporting infrastructure for the USGCRP deserve special attention.

USGCRP Observational Strategy

The USGCRP requires an **integrated observational strategy** in which the choice of tools and approaches is driven by scientific needs and reflects an appropriate balance between in situ and remotely sensed observations to produce integrated information products for use by the research community and decisionmakers in the public and private sectors.

Recommendations

- The USGCRP should develop and implement a new **integrated observational strategy** that

  - identifies the **key scientific questions** to be addressed, characterizes the required measurements, devises the most appropriate, cost-effective observational system to secure them, and maintains the programmatic discipline required to ensure balance within that system;
  - in close collaboration with the scientific community, identifies the needs for **long-term observing systems** and addresses the many difficult problems involved in their maintenance and the archiving of their data, utilizing scientific symposia and publication in the open literature as essential elements in this complex task; and
  - takes advantage of advances in technology such as **unmanned aircraft and small satellite systems**, where appropriate, to support observational and process research needs.

NASA's Earth Observing System

The National Aeronautics and Space Administration (NASA) Earth Observing System (EOS) should reflect the integrated observational strategy called for above. A series of previous reviews reshaped the program and guided it toward more responsiveness to scientific needs, greater resiliency, and increased opportunities for the introduction of new technology. In the plans presented to the present review, smaller spacecraft were scheduled to follow the AM-1, PM-1, and Chemistry-1 (Chem-1) missions. Furthermore, there was a shift by NASA in 1994 and 1995 from a fixed series of 9 missions involving intermediate-class spacecraft to a mixed fleet of 21 missions exploiting small to medium-class spacecraft. Our review supports that trend.

The present review also has confirmed that continued evolution is essential for successful implementation of NASA's Earth Observing System; therefore, the capability for future evolution must be maintained. In keeping with the above recommendation that the USGCRP develop an integrated observational strategy, and in anticipation of the advancement in understanding that will be achieved during this first phase of the EOS program, NASA, in concert with the USGCRP community, should consider carefully the observational strategy appropriate for the post-2004 era. Specific consideration must be given to the balance between monitoring, which requires certain long-term, calibrated measurements, and focused process studies, which may be accomplished in shorter periods. NASA's plans for biennial assessments are consistent with this recommendation and should also help ensure that the near-term observational strategy remains technologically current and scientifically relevant.

The present review has concluded, however, that structural changes to the near-term EOS missions beyond the limits achieved in the 1995 reshaping exercise would cause severe program dislocations. Further budgetary reductions or imposed constraints on technical options could mean the elimination of key sensors, slips in schedule, loss of data continuity, and the elimination of advanced technology development that could enhance future research and lower costs. Our review has concluded that a shift to smaller platforms for the first group of instruments would be premature, since it could eliminate key measurements.

As a result of technological advances, new scientific insights, programmatic changes by NASA in 1994 and 1995, and the evolving needs of the USGCRP as a whole, it is now appropriate to rebalance the program across space assets, in situ measurements, modeling and process studies, and the data and information management system. This rebalancing must be done carefully and must fully recognize the importance of certain calibrated long-term measurements for the USGCRP. The basis for this rebalanced EOS observational strategy is the 1995 reshaping of NASA's Earth Observing System.

Recommendations

- The USGCRP as a whole, and NASA's Mission to Planet Earth (MTPE) Program specifically, should maintain a **science-driven** approach to observation and information

technology that employs current technology while investing in the development of new technology with clear applications to support the program's specific scientific priorities.

- NASA should implement most of the **near-term components** of MTPE/EOS, including Landsat 7, AM-1, PM-1, and the Tropical Rainfall Measuring Mission (TRMM), **without delay** or reduction in overall observing capability.

- In situ observational programs, process studies, and large-scale modeling activities should be expanded (e.g., through **coordinated field programs** focused on high-priority scientific issues and utilization of advances in technology).

- NASA should develop **advanced technologies to reduce the costs of continuing the essential observations** initiated by the AM-1, PM-1, and Chem-1 missions.

- Because global mapping of tropospheric ozone is central for understanding and monitoring changes in the chemistry of the troposphere, the tropospheric component of the Chemistry-1 mission should be focused on **global measurements of tropospheric ozone** and its precursors in conjunction with the international ozone network.

- NASA should evaluate the capabilities of both space-based and in situ approaches to define the best scientific framework for obtaining critical information on ozone precursors in order to interpret tropospheric ozone trends. This evaluation must involve a wide spectrum of the scientific community. In addition, the evaluation should consider the critical aspects of the coupling between the chemistry of the troposphere and the stratosphere and the contributions from the European ENVISAT mission. An overall need to simplify and focus the Chem-1 mission and thereby reduce its cost and complexity must be recognized; however, **the Chemistry-1 mission should not be delayed**.

Coordination with Other Space Remote-Sensing Programs

Convergence of observing activities among the programs of U.S. agencies and those of other nations offers the potential for significant savings. However, the current convergence planning process does not have the charter or authority to consider the scientific requirements of USGCRP.

Recommendations

- Science requirements should be considered for inclusion in the specifications for the converged NOAA/Defense Meteorological Satellite Program system.

- In 1996, a **scientific and technical review of the federal convergence activities** should be conducted with special attention to their connection to the USGCRP.

Small-Satellite and Advanced Technologies

Those small satellites that have relatively low costs and short development times may provide mission and programmatic flexibility that can stimulate innovation. They can also provide a means to introduce new technology and conduct focused observing missions. The reshaped 1995 MTPE/EOS program anticipates the application of such satellites where appropriate. In some cases, physics, economics, and engineering constraints may preclude the application of small satellites. A balanced architecture for MTPE employs satellites of various sizes as appropriate to scientific needs.

Recommendations

- NASA should explore the possibility of using **advanced technologies** on small satellites for measuring tropospheric aerosols and winds, soil moisture, and other key parameters through laser, radar, and other advanced technologies.

- The Earth sciences component of the New Millennium Program (NMP) should be **integrated** into the Mission to Planet Earth Program; it should be science driven and not treated as a separate technology program.

- A small-satellite program should recognize two **linked challenges**:

  1. to develop capabilities that will **lower mission costs**; and
  2. to develop measurement capabilities that **advance our observational capabilities** in critical priority areas in Earth system science and global change.

Again, however, any shift in observational strategy and its implementation must be done carefully and must fully recognize the importance of certain calibrated long-term measurements for the USGCRP.

Practical Applications of EOS

MTPE/EOS, including the TRMM, Landsat 7, AM-1, PM-1, Chem-1, and the associated smaller missions, represents significant advances over previous space observation systems. The capabilities of these systems will contribute to practical applications such as natural hazards mitigation, water resources management, and food and fiber production, as well as advances in the Earth sciences.

Recommendation

- The capabilities of MTPE/EOS should be exploited fully via enhanced public access to the information products.

EOS Data and Information System

The EOS Data and Information System (EOSDIS) is an essential component of the EOS program for linking space and ground observations and converting them into accessible geophysical information that will contribute to new scientific understanding. Originally designed by NASA as a centrally controlled and operated system to meet ambitious performance and reliability requirements, the system was redesigned after a National Research Council (NRC) review as a logically distributed system based on a client-server model in order to accommodate evolving computer system concepts and technologies.

Despite this improvement, current performance requirements, a centrally controlled system of stand-alone computer centers, and an extensive engineering and management superstructure are stressing the bounds of affordability. Moreover, the committee is concerned that the management structure may not be sufficiently flexible to meet rapidly evolving scientific needs and opportunities. The current system should therefore be reconsidered in light of technological opportunities and possible management efficiencies.

The present problems with EOSDIS are not related to engineering concepts. Instead, the concerns are much more fundamental and are related directly to the conceptual model of its operations and management. For EOSDIS to succeed in enabling new levels of achievement in the Earth sciences and applications in a wide range of activities in the public and private sectors, its management must be open and community based. That is, the community of researchers and users must take the lead in making key decisions, and the assignment of responsibilities and evaluations of performance must be based on peer review. The system must encourage innovation and creativity through broad participation of the scientific, public, and private sectors.

Recent progress in redesigning the EOSDIS architecture, coupled with extraordinary new capabilities in computer telecommunications and recent experience by the scientific community in the management of large and diverse data sets, now permits a significant change in the

conceptual model that governs the management and operation of the system. Thus, although the initial processing (e.g., through geo-located and calibrated radiances at the spacecraft) of the data flowing from spacecraft should remain with NASA and could be conducted largely at existing centers, the subsequent processing and creation of products useful in science and applications should be distributed widely and thereby take advantage of the concepts and technology involved in the rapid growth of the Internet and the World Wide Web.

Thus, the current distributed client-server design of EOSDIS is responsive to community needs, and its engineering development, and should continue. However, the Committee on Global Change Research believes that the **EOSDIS management and operations concept** should be redefined to involve the broad user community effectively.

Recommendations

- The components of the EOSDIS now under development for flight control, data downlink, and initial processing should be retained but **streamlined**.

- Responsibility for product generation, publication, and user services should be transferred to a **federation** of partners selected through a **competitive** process open to all.

Representative actions to respond to these recommendations are given in Appendix F with the aim of aiding NASA, the EOS investigators, and EOSDIS contractors in designing and conducting a collaborative study of the feasibility and cost of the proposed approach.

Clearly these recommendations imply a major change in EOSDIS management and operations. Under the proposed concept, the initial processing of observational data from EOS spacecraft would remain the responsibility of NASA. After a transition period, however, the responsibility for generating products and accounting for interdependencies among instruments would be distributed through a competitive process to a federation that might include government, academic, and private sector entities. Members of the federation would receive geophysically located, calibrated radiances over the Internet or via overnight express; process the data to higher levels, resolving any necessary interdependencies; create appropriate data products; and make them available to users over the Internet or by shipment of media. Among the higher-level data products that would be produced and distributed in this manner would be EOS Standard Data Products.

To be successful, this approach must incorporate community leadership and acceptance of responsibility in decisionmaking, and it must encourage innovation and creativity by providing users with ready access to scientifically meaningful data sets. The new approach must be based on powerful incentives, permissive standards that encourage wide participation and electronic publication of results, and meaningful criteria for assessing the performance of the partners

responsible for data products and user assistance. In implementing this recommendation, there must be a clear recognition of the overriding importance of long-term maintenance and availability of the data, including the original Level-0 data, the geophysically located and calibrated radiances, and the higher-level products.

This intellectually inclusive approach will stimulate scientific creativity and innovation while providing increased return on the national investment. Moreover, it will create a strong foundation for the broader Global Change Data and Information System. It will generate a new approach to the interactive management and use of distributed data sets that, with an appropriate set of standards and protocols, will provide a new capability for collaborative and innovative exploitation of complex arrays of data and information in a wide range of public and private endeavors.

CONCLUDING THOUGHTS

The U.S. Global Change Research Program (USGCRP) recognizes the intellectual evolution of Earth system science and the magnitude of the scientific challenge of understanding and predicting global change. The scientific foundations, motivations, and goals of the USGCRP remain valid guides for the conduct of the program. Nevertheless, because of scientific advances, emerging technologies, and new concepts of effective management, the program can be refined in significant ways to become scientifically stronger, to be balanced better, and to produce greater return on the national investment. The Committee on Global Change Research, assisted by the workshop participants, assessed the USGCRP and NASA's MTPE/EOS program in the context of these new scientific and management insights and identified a recommended path for the future of the USGCRP. The proposed rebalancing of the program would offer the potential for significant economies (e.g., by simplifying the Chem-1 mission, by streamlining the data downlink and initial processing of EOSDIS, and by employing a federation of partners in EOSDIS for product generation). To ensure scientific success, it is necessary to direct resources toward (1) expanding in situ observations, process studies, and large-scale modeling; and (2) developing advanced technology to reduce the costs of second- and third-generation missions and to open new scientific opportunities.

The Committee on Global Change Research believes that this rebalancing of resources is central to the recommendations in this report.

Appendixes

The following appendixes provide short summaries of the deliberations of the working groups on the four scientific areas of the U.S. Global Change Research Program (USGCRP) and on the role of the National Aeronautics and Space Administration (NASA), Mission to Planet Earth/Earth Observing System (MTPE/EOS) and EOS Data and Information System programs in the context of the overall program. These documents were written by the designated working group chairs and reflect their sense of the views of working group participants, further illuminated by extensive plenary discussions in the course of the workshop. These documents provide a window into the information, analysis, and discussion drawn on by the committee in formulating its conclusions and are presented here to provide a background for the preceding report. However, they do not represent approved conclusions or recommendations of the workshop or of the responsible committee. The chairs of the six working groups are also preparing a set of more complete interim working documents that describe their deliberations in more detail and will be used as critical input to the second phase of the comprehensive review of the USGCRP.

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A

END-TO-END SEASONAL TO INTERANNUAL PREDICTION

Working Group Participation

Edward S. Sarachik, *Chairman*

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Moustafa T. Chahine

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Piers J. Sellers

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Soroosh Sorooshian

Peter J. Webster

Designated Federal Liaison: J. Michael Hall

Rapporteur: Frank Eden

WORKING GROUP SUMMARY

Edward S. Sarachik, *Chairman*

In terms of climate prediction, the last ten years have witnessed a revolution in our ability to observe, understand, and predict a year in advance the fundamental dynamics of the El Niño/ Southern Oscillation system. Success to date suggests that further research and development could lead to climate predictions that can provide advanced information to reduce the impacts of such destructive natural climate fluctuations as droughts, which lead to forest fires and crop failures; floods, which lead to loss of life and stoppage of river commerce; and heat and cold waves, which lead to human misery and deprivation.

We make a prediction every time we expect this year's summer to be basically the same as last year's. It is this expectation of the regular return of the seasons that is confounded when unusual spells of weather cost us time and money because our expectations turn out to be false. The need to predict, when possible, the ***actual*** state of the climate, months to a year or so in advance, motivates programs on seasonal to interannual prediction. What we now have the ability to accomplish motivates a great deal of scientific observation, research and modeling. The science is fundamental, yet the payoffs are short term and tangible.

Progress by a determined community of government and university meteorologists, oceanographers, and hydrologists with multiagency support (led by National Oceanic and Atmospheric Administration (NOAA) Office of Global Programs) has been rapid and remarkably successful: We already have begun to predict aspects of El Niño in the tropical Pacific, and these forecasts have benifited countries affected by El Niño (Peru, Brazil, Australia, Chile, and Columbia, the Philippines, and the U.S. Pacific Islands). Progress over the next few years will determine whether this predictive capability can be developed fully for use within the United States.

In the early days of climate research, science was the province of a few agencies, often with diverse objectives. The U.S. Global Change Research Program (USGCRP), aided by the Office of Management and Budget (OMB), allowed the agencies to focus their resources and to function in a coordinated way with advice provided by the National Research Council (NRC). As a result of these programs on seasonal to interannual variability, we have moved from a time in which the El Niño phenomenon could barely be observed, to a time in which data on the actual state of the surface and subsurface tropical Pacific to a depth of 500 meters, along with predictions based on these observations, are accessible to any researcher via desktop computers.

Science Questions

The creation and evolution of USGCRP programs on seasonal to interannual variability are based on four fundamental scientific questions:

1. *Where* is there significant seasonal to interannual variability in the Earth's climate system, and what are the patterns of this variability?

2. What *mechanisms* underlie this seasonal to interannual variability, and how do they differ across space and time?

3. What are the *effects* of seasonal to interannual variability, for example, on economic stability and competitiveness; on agriculture, natural resources, water resources and hydrology, trade routes and transportation, etc.; and on natural hazards such as floods, droughts, forest fires, heat waves, and consequent health effects?

4. How *predictable* are seasonal to interannual climate variations and their effects?

USGCRP RECORD IN UNDERSTANDING SEASONAL TO INTERANNUAL CLIMATE VARIATIONS

Through programs developed under the USGCRP (with the cooperation of OMB and support from Congress)--primarily TOGA (Tropical Oceans Global Atmosphere), its successor program CLIVAR/GOALS (Global Ocean Atmosphere Land System), and GEWEX (Global Energetics and Water Experiment)--we have *begun* to understand seasonal to interannual climate variations in limited regions of the Earth, especially the phenomenon referred to as El Niño. We can now see, understand, and predict (to a degree usable for some regions of the world) the climate variations that characterize El Niño. We have also begun to appreciate the role of land processes and hydrologic systems in seasonal to interannual climate variability or predictability.

Some remarkable achievements over the last ten years have pioneered short-range climate prediction and indicated a path to the eventual prediction of seasonal to interannual climate variations over the U.S. These include the following:

- development of a mechanistic understanding of the El Niño/Southern Oscillation and its influence on the climate system;

- development of coupled atmosphere-ocean models for the tropical Pacific capable of simulating the El Niño/Southern Oscillation (ENSO) phenomenon and its influence on the climate system;

- building, deployment, and maintenance of a basin-wide multinational observing system with data freely available in real time (see Figure A-1);

- planning, implementation, and analysis of a multinational study designed to quantitatively define the interaction of the atmosphere and the ocean in the western equatorial Pacific;

- development of usable forecasting skills for sea surface temperature variations and rainfall in the tropical Pacific;

FIGURE A-1 Tropical Pacific Ocean Observing System

- design and partial implementation of an end-to-end prediction system that will bring together observations and models for us in regions affected by El Niño;

- the ability to extend forecasts to a month in advance for excess rainfall and floods in the Mississippi basin by use of high-solution models;

- identification of the remote effects of ENSO and the local effects of land surface on the U.S. drought of 1988;

- planning of a multinational study to investigate rainfall patterns and variability and interactions with the land surface in the Mississippi basin;

- deployment of a major radiation-observing network in Oklahoma and Kansas to calibrate climate models and satellite measurements;

- initiation of activities to expand both the time range of and the spatial extent of prediction to greater areas of the globe including land processes;

- demonstration, principally by large-scale field experiments, of the importance of soil and vegetation processes in controlling land surface-atmosphere exchange of energy, water, and carbon, satellite data are now being used to define the continental patterns of these exchanges;

- initiation of ensemble forecasting to explore the effects of El Niño variability over the U.S., and extension of the predictability of seasonal to interannual variations over U.S. regions known to be affected by El Niño (see Figure A-2).

- demonstration of the benefits of El Niño forecasting to the countries and regions affected by it.

These accomplishments have arisen from focused U.S. contributions to international programs, including TOGA, GOALS, and GEWEX. However, a great deal of activity in USGCRP agencies on seasonal to interannual climate has not been part of these focused efforts and therefore has not been nearly as effective in advancing the highest priorities.

OPPORTUNITIES FOR USGCRP IN SEASONAL TO INTERANNUAL CLIMATE VARIABILITY AND PREDICTABILITY

Based on the results of the TOGA program, the research community believes that future opportunities for the USGCRP will best be achieved in the context of

- **a demonstration research project for an end-to-end seasonal to interannual prediction capability, initially involving El Niño.**

NORTHERN HEMISPHERE WINTER

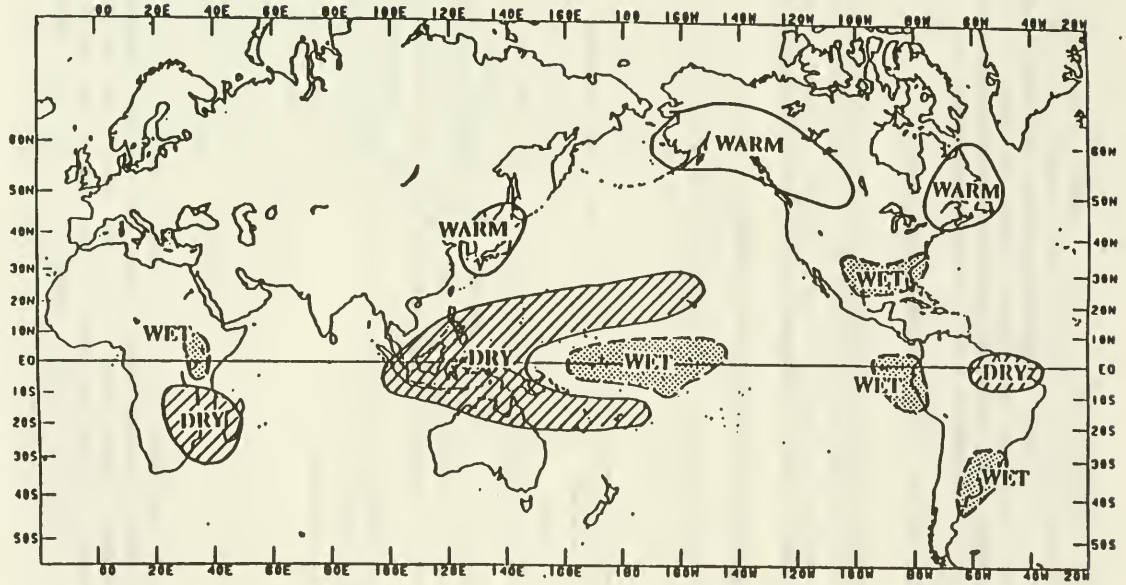

FIGURE A-2

Such a demonstration project is reflected in national and international global change program documents that describe the need for research programs, such as CLIVAR/ GOALS and GEWEX, and call for the establishment of an international research institute (IRI) for seasonal to interannual climate prediction. Planning documents for elements of the World Climate Research Program (WCRP) and the U.S. Seasonal to Interannual Climate Prediction Program (SCPP) point to the establishment of an IRI as an important mechanism to

1. accelerate the application of existing predictive skills;

2. ensure multinational support for a program of seasonal to interannual climate prediction, including critical support for the required observing system;

3. identify scientific priorities associated with extending predictive capabilities; and

4. guide the allocation of resources accordingly.

The broad outlines of such a demonstration project can be diagrammed as shown in Figure A-3.

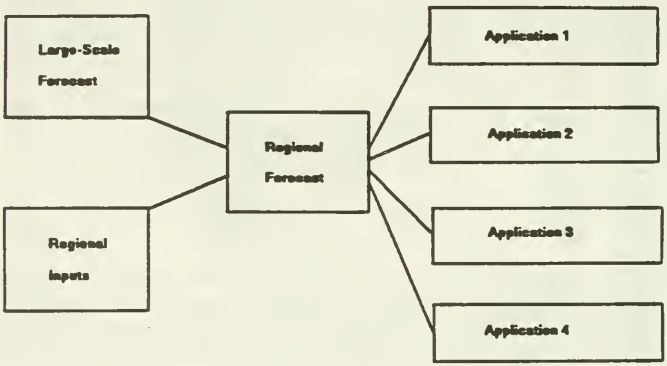

FIGURE A-3

Since all useful forecasts are local, a large-scale forecast is, by itself, not sufficient for practical application. Local data (models, statistical data, etc.) must be added to the large-scale forecast to produce a regional forecast. This regional forecast is then used for application to a sector. Different applications may require different types of local forecasts: for example, applications to fisheries may require, among other things, ocean temperature, whereas applications to agriculture and water resources will require, among other things, rainfall amounts.

In this context, an end-to-end prediction system can be defined as consisting of the following steps:

- A **model** must be developed to make the predictions.
- **Data** must be quality controlled and assimilated into a form the model can accept.
- **Initialization:** The data and the model must be combined to provide an optimal estimate of the state of the coupled system.
- **Large-scale prediction:** One, and perhaps an ensemble, of predictions must be made.
- **Evaluation:** The data must be used to determine the accuracy of the forecast and provide an objective measure of skills and uncertainties.
- **Assessment:** The impacts of seasonal to interannual variability and must be examined, an appropriate regional site and scale must be chosen.
- **Regionalization:** Regional data and models must be combined to provide data products for input to forecasts.
- **Regional forecasts:** Regional data products must be combined with the large-scale forecast to provide a regional forecast.
- **Applications:** Regional forecasts can be applied to different sectors.
- **Effectiveness of applications:** Appropriate ways must be developed to distribute and communicate information (including uncertainties) about seasonal to interannual variability, prediction, and applications to a broad user community.
- **Evaluation of applications:** The impact of the applications and the effectiveness of the actions taken must be evaluated.

Implementation

Implementation of the concept of end-to-end prediction requires a number of things that can be diagrammed as shown in Figure A-4.

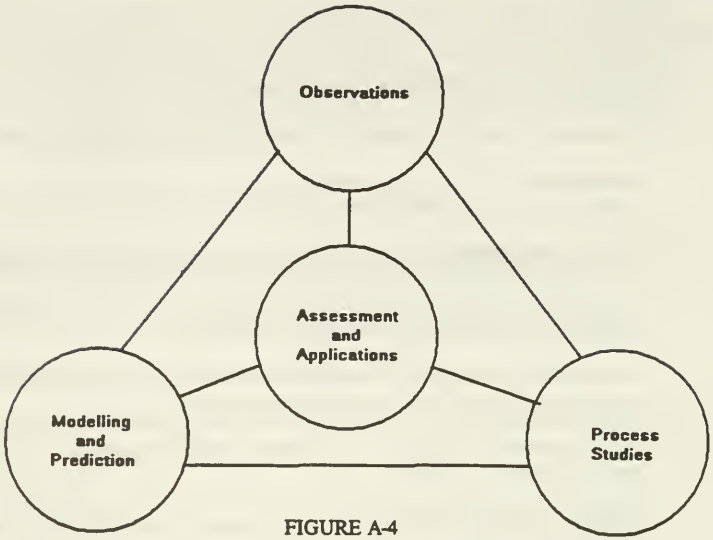

FIGURE A-4

The strong interaction and balance among all the elements in the figure are crucial. End-to-end seasonal to interannual prediction requires the development of coupled atmosphere-ocean-land models. It requires that observations be available and a procedure developed for initializing the forecasts. It means that remote and in situ observations must be combined for this initialization and that an efficient data system must be established for this combination. It requires a procedure for validating predictions. It requires that poorly understood or modeled processes be investigated and sets priorities for these processes. Since climate information, to be useful, must be brought down to the local level, it requires adding local information and making region-specific forecasts. Then, the sector of application and its normal mode of operation in the absence of additional information must be identified and understood. Finally, the information must be combined with the forecast and presented to the user in a way that guarantees maximum utility.

The basic implication of this concept is that it guides, in a focused way, what needs to be done; provides a measure of the value of an activity in terms of its role in the end-to-end system; indicates gaps or imbalances in the activities (what is not being done); provides useful results on both a short-term and an ongoing basis; and has a built-in means of evaluation: the skill of prediction and the success of the applications. Conversely, this end-to-end activity is integral: no part of it can be compromised without affecting the ultimate skill of the prediction and the usefulness of the applications.

The working group participants identified some priorities within individual components of this integrated program on seasonal to interannual climate prediction.

Models

Research is needed to enhance the understanding of a crucial, but poorly understood, aspect of climate models: (1) land-atmosphere interactions, with initial emphasis on land-atmosphere interactions over the Mississippi and the Amazon basins, and (2) the characteristics and predictability of precipitation in this region and other land regions that affect seasonal to interannual predictability (GEWEX).

Observing System

General Principle

A general observing system for end-to-end predictions must be some *combination* of in situ and remote observations and must lead to model-assimilated data.

The reasons for this principle are numerous: Remote systems generally require surface information continuously. This information is used for continuous calibration and to ameliorate gaps that always arise from remote observations. Conversely, in situ observations can never be global; they require remote measurements to achieve global coverage. Both types of observations must contribute to the initialization and validation of predictions and, therefore, to a model-assimilated data product.

We can identify the priorities for seasonal to interannual prediction:

- Atmosphere: upper air data as given by the World Weather Watch--precipitation, water vapor distributions and profiles, top-of-the-atmosphere radiation, cloud and aerosol properties and distributions in the vertical and horizontal;

- Ocean: *sea surface temperature, sea surface winds, upper ocean subsurface temperatures,* precipitation, sea level, salinity, sea ice

- Land: soil moisture, soil type, topography, vegetation, surface temperature, precipitation, snow cover, runoff, and fields of surface radiation coordinated with top-of-the-atmosphere radiation.

The quantities are not prioritized among atmosphere, land, and ocean, and only for the ocean are relative priorities identified (italicized quantities represent the highest priorities). Note that precipitation occurs in all three lists. Maintenance of the CLIVAR/GOALS observing system in the tropical Pacific and its appropriate expansion combining in situ and remote observations (including Mission to Planet Earth) over other oceans and over land are essential.

Process Studies

Process studies can be observational, theoretical, or computational and can range from pencil-and-paper calculations to large observational field programs. In order to apply to end-to-end prediction, they must focus on those inadequacies in the models, observations, or applications that affect the skill of prediction or the success of applications.

The skill in seasonal to interannual prediction within the U.S. is still insufficient to be used effectively but it is being developed in a planned, phased process. This process begins by further improving the skill of predicting of El Niño in the tropical Pacific; then expanding the regions of application around the tropics (including the monsoon regions of North America, especially Arizona, Texas, and New Mexico; South America; and Southeast Asia); next investigating predictability in midlatitude areas (including the U.S. West Coast and Southeast) that derive their predictability from the remote effects of El Niño; and finally, investigating whatever predictability may be further exploited from atmosphere-ocean-land interactions totally outside the tropics (CLIVAR/GOALS and GEWEX).

These process studies are best pursued via U.S. contributions to the high-priority international programs CLIVAR/GOALS and GEWEX, and via successful implementation of the U.S. SCPP, including establishment of an IRI.

EVALUATION OF USGCRP PROGRAM MANAGEMENT

Accomplishments thus far have resulted in a new paradigm in which the concept of end-to-end prediction motivates and guides all program components and determines the priorities and balance among program elements.

The concept of end-to-end prediction can also be used to focus and evaluate relevant research by imposing a discipline on the process and defining the priorities for a carefully balanced program. This balance is crucial: since all elements depend on each other, no element can be compromised without damaging the entire enterprise. It presents a method of R&D in which success can be demonstrated by the development of forecast skill and by the money and lives saved by applications of predictive information. The program requires careful coordination, good advice and oversight, and a stable and balanced funding profile, with focused contributions by the agencies involved in seasonal to interannual prediction. This country has an enthusiastic and able body of scientists eager to tackle the scientific problems involved in developing end-to-end prediction on these time scales. The return for investment now will pay off in the short run and eventually lead to a permanent prediction capability that will benefit the entire country.

In this context, the working group identified some program management principles that must apply in supporting and managing a demonstration research program on end-to-end seasonal to interannual prediction.

Success requires a management structure in USGCRP (with OMB, the Office of Science and Technology Policy (OSTP), and the Congress) that will

- ensure that the highest-priority programs are protected both within and between agencies;

- ensure that support is focused on the highest-priority programs and that balance is maintained among program components, and

- ensure that participating agencies contribute (or not withdraw) resources for the highest-priority programs.

The working group emphasized that these requirements are not currently being fully met.

OPPORTUNITIES FOR INTERACTION WITH OTHER ELEMENTS OF USGCRP

Seasonal to interannual climate variability interacts strongly with other elements of the USGCRP. Only a few examples are given here.

Decadal to Centennial Variability and Change

The attachment to this appendix provides some details on the connections between research on seasonal to interannual climate variability and investigations of decadal to centennial climate change. Examples include the following:

- El Niño has a predominantly interannual time scale but is also modulated on decadal time scales. This decadal modulation has teleconnection to higher latitudes and has been shown to be responsible for the greater warming over land and cooling over ocean during the winter than during the summer. Therefore, El Niño processes are an important source of decadal climate variability.

- The subtropics of the Atlantic have a dipole in sea surface temperature that helps determines the location of rainfall in both northeastern Brazil and the Sahel. The variability of this dipole is both interannual and decadal and therefore is a natural contact point between the two scientific areas.

Atmospheric Chemistry

Since cumulus convection in the tropical Pacific has the time dependence of El Niño, and since it both directly transports water vapor (and other trace gases) into the stratosphere and affects the height of the tropopause, there will be a modulation of stratospheric- tropospheric exchange.

- Tropospheric temperature, especially in the tropics, varies with El Niño and, through temperature and water vapor, affects all aspects of tropospheric chemistry.

- Under normal conditions, the tropical Pacific is a net source of carbon dioxide and contributes 1 gigaton per year to the atmosphere. During warm El Niño conditions, this flux of carbon dioxide is severely reduced or completely eliminated. El Niño modulations of carbon dioxide are therefore important components of the natural carbon budget of the atmosphere.

Large-Scale Ecology

- All growing systems near the surface respond to sunlight and water at the surface. Interannual modulations of both water and sunlight affect the characteristics and response of these ecological systems.

- Extreme conditions during El Niño (e.g., rainfall in the normally arid Peruvian coastal plains) can stress ecosystems used to more subtle variations.

MISSION TO PLANET EARTH/EARTH OBSERVING SYSTEM (MTPE/EOS) AND SEASONAL TO INTERANNUAL PREDICTION

1. GOALS, GEWEX, and SCPP look to MTPE to help provide the capability to expand prediction skill around the globe and to higher latitudes (including land), and to better assess the impacts of seasonal to interannual variability. It can do this by

    - measuring the high-priority quantities subject to the principle that all USGCRP observations are combinations of in situ and remote measurements leading to model-assimilated data products when possible and desirable,

    - guaranteeing the continuity and quality of measurements by overlapping in situ and remote measurements, overlapping remote measurements, and continuing in situ validation of remote measurements, and

    - supporting and enhancing the core programs GOALS, GEWEX, and SCPP, including the IRI.

2. The Earth Observing System/Data Information System (EOSDIS) should provide *products* that

    - contribute to data assimilation for initialization of end-to-end seasonal to interannual predictions;

- are useful and easily accessible for assessing the impacts and validating predictions of seasonal to interannual variability and the applications of such predictions; and

- combine in situ and remote data as appropriate.

3. EOSDIS should include a *process* to characterize user needs and design useful products for them.

CONCLUSION

The U.S. public responds to what it reads and experiences and has come to expect predictions of heat waves, destructive hurricanes, excess rainfall leading to floods, and spells of drought. The skill for seasonal to interannual prediction within the United States at the moment is too low to be used effectively. However, it is being developed by a planned, carefully phased process that begins by concentrating on regions where predictability has been proven, particularly El Niño in the tropical Pacific. This process then concentrates on international programs such as CLIVAR/GOALS and GEWEX, and on implementation of the U.S. SCPP, including the IRI.

ATTACHMENT

Intersection of Seasonal to Interannual and Decadal to Centennial Climate Variability and Prediction

Roger B. Lukas

The past few years have seen ENSO variations in the tropical Pacific unlike anything in the past 100 years. The probability of observing this type of variability by chance is 1 in 2,000 if the recent climate record is stationary with respect to S-I variability. Thus, the inescapable conclusion is that S-I variability is nonstationary, and it remains to determine whether this is a characteristic of natural variability on longer time scales or whether it is related to enhanced greenhouse warming.

Recent analysis showed that the amplitude and phase of the annual cycle in the SOI have varied substantially during the 1900s. It is well established that the existence and character of model ENSOs depend on the annual cycle that is either produced by the model or specified a priori. One might view ENSO as a perturbation of an unstable annual cycle.

A recently discovered global mode of the ocean-atmosphere-land system involving winter warming over northern land masses and winter cooling over northern oceans showed that surface temperature anomalies varied out of phase on short time scales, but they have been locked into a warm phase over land masses for at least the past two decades.

Together, these results suggest that decadal time-scale processes are interacting with ENSO. Further, it appears that these modulations are impacting the recent prediction skill for ENSO. Thus, it is very important for the seasonal to interannual climate component of CLIVAR and USGCRP to work in collaboration with the decadal to centennial climate component to understand the mechanism(s) responsible for these modulations of ENSO.

Some hypotheses can be advanced to explain these and related observations. Two involve tropical-extratropical linkages within the ocean, operating on much longer time scales than such linkages in the atmosphere. One hypothesis involves long oceanic Rossby waves generated along the eastern boundary of the Pacific during ENSO, and their subsequent propagation westward across the basin and interaction with the atmosphere through sea-surface temperature (SST) variations. Another hypothesis involves the interplay of the shallow thermohaline overturning cell in the North Pacific coupling the tropical and subtropical wind-driven gyres, with anomalous heat and freshwater flux forcings in the subtropical gyres (forced in part by ENSO) manifest later as equatorial thermocline anomalies.

A combination of monitoring, modeling, and process research is appropriate to pursue one or more of these hypotheses. Such an integrated approach to understanding the decadal modulations of ENSO provides motivation for continuing observations in a research context. Existing elements of the GOALS (former TOGA) observing system and the ongoing World Ocean Circulation Experiment (WOCE) program already provide a large-scale monitoring context for the upper Pacific Ocean. A sequence of process studies is proposed to address the processes that are critical to these (and other possible) hypotheses in order to ensure that they are properly captured in coupled models that can be used to rigorously test the motivating hypotheses. Such an approach has been used quite successfully during TOGA.

B

ATMOSPHERIC CHEMISTRY

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WORKING GROUP SUMMARY

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Changes in the chemical composition of the atmosphere on the global scale are not hypothetical. They have been occurring rapidly over the last hundred years. Increases in carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and chlorofluorocarbons (CFCs), and decreases in stratospheric ozone are well documented. Volcanic dust has been observed to rise to the stratosphere and impact the global climate for periods of months to years. Surface ozone abundances in industrialized regions have changed dramatically as a result of surface input of NO_x and volatile organic carbon compounds (VOCs), but changes in midtropospheric ozone on the global scale are less certain. The release of anthropogenic nitrogen and sulfur compounds has led to an increase in the acidity of precipitation and has increased the deposition of critical nutrients and toxins in many regions of the Northern Hemisphere.

The observed changes in the chemical composition of the troposphere and stratosphere are having adverse affects on human enterprises, including agriculture and human health; they also affect the productivity of natural ecosystems and have increased the radiative forcing of climate.

In the last decades, global change research has been successful in leading to a scientific understanding of a number of these changes. For example, the well-documented year-by-year increases in CO_2 have led us to recognize the ability of humans to perturb the global Earth system through combustion of fossil fuel and deforestation. In addition, the Antarctic ozone hole was discovered and diagnosed, and its cause is now largely understood to be the emission of halocarbons. These advances occurred because of the existence of a strong research capability in observations, theory, and laboratory studies that could be focused rapidly on these problems. Nevertheless, major scientific problems involving changes in atmospheric composition remain to be resolved. For example, the role of marine versus terrestrial systems in the uptake of anthropogenic CO_2 is not yet understood. Understanding of the balance between the two is required to project future CO_2 abundances in the atmosphere. Similarly, the understanding of ozone changes in the lower stratosphere and troposphere is incomplete and yet is essential to comprehend the relative importance of the various causes of climate change.

Among the key scientific questions are the following:

1. Although the processes responsible for the formation of the Antarctic ozone hole are largely identified, we need to understand why the observed ozone depletion at midlatitudes in the lower stratosphere is greater than that derived from chemical models. A better understanding is important to predict future changes in the level of ultraviolet-B (UV-B) radiation at the Earth's surface over the next 10 years during which the maximum ozone losses will occur.

2. Although the global increases of trace gases such as CO_2 and CH_4 are well documented, we must assess the relative role of fossil fuels, land cover change, and natural ecosystems in controlling those patterns in order to accurately project trends into the future.

3. Although we understand the reason for the high levels of ozone over several regions of the world, we need to better establish the distribution of ozone in the troposphere in order to document and understand the changes in the abundance of global tropospheric ozone. This information is needed to quantify the contribution of ozone to the Earth's radiative balance and to understand potential impacts on the health of the biosphere.

4. Having recognized the importance of particles in the chemistry of the stratosphere, we must determine how aerosols and clouds affect the chemical processes in the troposphere. This understanding is essential to predict the chemical composition of the atmosphere and to assess the resulting radiative forcing effects in the climate system.

5. Finally, we must determine if the self-cleansing chemistry of the atmosphere is changing as a result of human activities. This information is required to predict the rate at which pollutants are removed from the atmosphere.

To address these questions, the coordinated research strategy based on observations, laboratory studies, and modeling needs to be sustained and judiciously focused. Surface-based observations of chemical concentrations are the key to long-term monitoring of chemical changes in the atmosphere. Similarly, measurements of exchanges among the terrestrial ecosystems, oceans, and the atmosphere are critical for understanding the inputs to and removal of chemical species from the atmosphere. Airborne measurements provide insights into the specific processes occurring at various levels of the atmosphere. Observations from space are the only practical way to provide global coverage of the atmosphere. Laboratory studies provide the fundamental information on the chemical reactivities of atmospheric species. Modeling provides a comprehensive statement of our understanding and is needed for the interpretation of global observations and the prediction of future changes.

Satellites have been essential for the global observation of ozone and other chemical species in the stratosphere and for our assessment of ozone trends, particularly in the Southern Hemisphere, where ground-based stations are sparse. Satellite observations of terrestrial ecosystems and the ocean have also been used to characterize their interactions with the atmosphere and hence their influence on its chemistry. Likewise, meteorological observations have been essential for developing chemical transport models. Space-borne observations will continue to be a necessary component of the observational program.

This coordinated research strategy is supported by contributions from several federal agencies, and the research is carried out in universities, federal laboratories, and the private sector. Maintenance of these capabilities is the most cost-effective strategy for addressing both the recognized and the unforeseen problems of the future related to the chemistry of the atmosphere.

These capabilities and research strategy have been built into the plans of the U.S. Global Change Research Program (USGCRP) and also those of the international scientific community as represented by the International Global Atmospheric Chemistry Program (IGAC) of the International Geosphere-Biosphere Program (IGBP) and the Stratospheric Processes and Their

Role in Climate (SPARC) Project of the World Climate Research Program (WCRP). Activities are being carried out to support international conventions and assessments of ozone and greenhouse gases.

The Earth Observing System (EOS) space program will provide important measurements to address global change issues related to atmospheric chemistry (e.g., lower-stratospheric composition). Not all key information, however, can be gathered from space (e.g., reactive nitrogen budget in the troposphere), and are required observations from other types of platform. Both components are necessary.

Observing Strategy

In addition to maintaining the above research strategy of field and laboratory process studies, monitoring, and modeling investigations, we conclude that the following specific foci are needed in an observing strategy:

Stratospheric Ozone and Other Chemical Compounds

The continued operation of TOMS-like and SBUV-like instruments is needed to determine future trends in the total ozone column abundance. It would be useful, however, to coordinate efforts at the international level, since similar measurements will be performed in Europe (e.g., GOME and later OMI) and in Japan. In order to address the most pressing scientific questions (e.g., processes affecting the evolution of ozone in the lower stratosphere), it is also important that SAGE, MLS, HIRDLS, and TES be implemented and launched as soon as possible. Among several important observed quantities, SAGE will provide information on the global distribution of aerosols and their size distribution (key to our understanding of heterogeneous chemical processes) and their variation resulting from potential future volcanic eruptions. MLS will provide global coverage of the abundance of reactive chlorine (key to assessing ozone depletion, especially in polar regions). HIRDLS will observe at high spatial resolution the distribution of ozone, several other molecules, and aerosols in the lower stratosphere and upper troposphere. This will be key to verifying chemical transport models and providing for the first time global observations of chemical and radiatively active compounds in the upper troposphere and lower stratosphere. TES will measure tropospheric ozone and provide information on its precursors.

The continued operations of field campaigns using aircraft such as the ER-2 and DC-8 National Aeronautics and Space Administration (NASA), the P-3 National Oceanic and Atmospheric Administration (NOAA), and the WB-57 National Science Foundation; ground-based observations using a variety of techniques; and balloon-borne instruments are essential to ensure a solid base of observational data in the next decade. In addition, it is essential that the observations be integrated into theoretical modeling studies.

Tropospheric Ozone and Other Chemical Compounds

To obtain essential information on the global distribution of ozone and to understand the processes responsible for changes in its abundance, the recommended strategy should involve the following simultaneous actions:

1. Extend the existing (but very limited) ozone network, which ideally should include on the order of 50 stations judiciously distributed worldwide, and provide ozone sounding and lidar observations on a regular basis.

2. Develop a TES instrument focusing on tropospheric ozone and other species that affect tropospheric ozone concentrations to work in conjunction with the international ozone network.

3. Conduct a number of in situ airborne campaigns designed to investigate the chemical and physical processes that affect ozone in the global troposphere. Several ongoing and planned regional studies can contribute to this global effort.

4. Integrate the above observations into complementary laboratory studies and theoretical modeling and interpretation.

As currently planned, MOPITT on EOS AM-1, which measures the global distribution of carbon monoxide, and hence provides information on tropospheric intercontinental transport and on biosphere-atmosphere interactions, is the only space experiment in the U.S. program addressing questions of atmospheric chemistry that will be launched before the next century.

Tropospheric Aerosols

Although it has been suggested that aerosols in the troposphere play a significant role in climate forcing, the quantification of this forcing has been hampered by a large number of uncertainties (e.g., aerosol mass scattering efficiencies, chemical and optical properties, formation processes). These questions will best be addressed through field campaigns, augmented by laboratory and modeling studies, and by "closure" studies conducted from aircraft or balloons and from surface stations.

Space observations will provide aerosol climatologies needed to calculate the radiative forcing, using a combination of AVHRR and Seawifs, augmented with data from POLDER (a French instrument flying on a Japanese satellite) and GOME (on ERS-2). Lidars on free-flyers will be very useful to gather information over both land and oceans.

CONCLUSION

In the scientific subject areas described in this appendix, information should be provided through appropriate international scientific assessments that describe and evaluate research results. The research and assessment plan delineated here would provide end-to-end service to the nation on key issues relating to atmospheric chemistry and must involve all scientific stakeholders. Just as atmospheric chemistry has provided timely information to decision makers in industry, government, and the public on stratospheric ozone change, so too can this research program continue to serve the nation's current and future information needs in this area.

C

ECOSYSTEMS

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WORKING GROUP SUMMARY

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Large-scale ecosystem studies are a rapidly maturing field of science, which under the impetus of global change research has had major successes over the past decade. Improvements in fundamental understanding of marine and terrestrial ecosystems and hydrology have already led to practical applications in weather and climate modeling, air quality, and improved water resources; forest, fisheries, and rangeland management; and natural hazards responses.

The principal questions in large-scale ecosystem science involve understanding the effects of changing land cover on land-atmosphere exchanges of carbon dioxide (CO_2), water, and energy, and consequent effects on climate and the carbon cycle. The synergistic instrument complement of the Earth Observing System (EOS) AM-1 and PM-1 platforms, combined with data from Landsat and other ocean-sensing satellites to document the roles of marine ecosystems in the carbon cycle, will satisfy in large measure the satellite data needs of the ecosystems community and will result in a massive improvement in the quality of remote observations.

Assessment and Future Requirements of the U.S. Global Change Research Program and the Mission to Planet Earth

Overall, the U.S. Global Change Research Program (USGCRP) has been successful in advancing the science and tools required for space-based assessment of ecosystem change. The ground- and ocean-based components of the program have had varying degrees of success. Elements linked to atmospheric science (biophysics and trace gases) have had the strongest programs. The more ecological (vegetation and land cover) and integrative (ecosystem manipulation experiments) components have been supported on an ad hoc basis. Extension of local understanding from process studies to regional and global scales requires modeling. This work has made major advances but is less well-developed than in situ or remote sensing aspects of the program. Fulfilling the goals of the USGCRP requires enhancement of integrative modeling and close coordination of modeling with ground-, ocean-, and space-based studies.

Areas of Success

- Field and theoretical studies have been carried out that have laid the foundation for understanding the role of vegetation and soils in weather and climate, and have advanced our methods for interpreting satellite data. Execution of the field experiments planned for the Mississippi and Amazon basins would complete this series of studies.

- Satellite observation techniques, ground-based observations, and models, have been developed that can determine changes in land cover type, as well as spatial and seasonal changes of vegetation.

- The role of nutrients in the large-scale interactions of ecosystems with the atmosphere has been elucidated. The effects of nutrients such as nitrogen and phosphorus now must be systematically incorporated into global models of land-atmosphere interactions.

- An ambitious program has been implemented to measure and model the sources and sinks of CO_2 and trace gases from biological and biomass-burning sources. This program will allow the development of an observing system to determine trends and patterns of emissions and uptake on continental scales.

- Oceanic time-series observations have revealed previously unknown year-to-year variations in coupled ocean biology, chemistry, and physics that are, linked to climate variability.

- Regional ocean carbon studies have quantified seasonal marine ecosystem effects on atmosphere-ocean CO_2 exchange and El Niño-related variations in the equatorial Pacific sources and sinks of CO_2.

- Impacts of climate change and variability on agricultural and forest ecosystems have been modeled.

Critical Work in Progress That Should Be Continued or Enhanced

- Experiments to determine the long-term ecosystem-level effects of rising CO_2 in forests and agricultural crops and grasslands have just begun; these experiments must be sustained and effectively linked to global change modeling efforts.

- Observations of atmospheric CO_2, its isotopes, and oxygen are crucial for quantifying processes within the carbon cycle, these measurements are at a minimal density for success and must be expanded over the continents.

- The ocean CO_2 survey must be completed, and associated modeling efforts enhanced, in order to fully assimilate this information into global climate models.

- The ability to determine land cover changes from space has been demonstrated in regional studies. Global implementation, including the expansion of international partnerships, is required.

- Regional case studies of human land cover change have begun. Efforts to understand how changes in population, technology, and development affect land cover must be developed and linked to global-scale models.

Several Areas Requiring Special Emphasis

- Great opportunity for understanding the role of ocean ecosystems in the global carbon cycle has been lost with the nearly decade-long hiatus in ocean color data. Launch of the SeaWiFS instrument must be given high priority.

- Data sets must be developed for the use, intercomparison, and testing of models of terrestrial vegetation and productivity.

- Preliminary exploration is necessary of the potential for emerging and possibly commercial satellite measurement technologies, especially for managed ecosystems such as agriculture and forests.

- Implementation of vegetation analysis transects, utilizing existing and new field studies, is required to characterize the large scale relationships among climate, vegetation, and human activity.

D

DECADAL TO CENTENNIAL CLIMATE

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WORKING GROUP SUMMARY

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The last decade of research has demonstrated two important points. First, significant climate variability on time scales of decades to centuries has occurred in the past and will likely continue into the future. Second, the potential exists for significant changes in climate and climate variability over the next decades to centuries in response to human activities.

Substantial advances in climate understanding and prediction have occurred over the last decade:

- There have been recognition and documentation of the scope of natural variability, involving (1) remarkable records of variability and rapid change from ice cores, tree rings, and corals; and (2) determination, by means of models, that ocean-atmosphere interactions can lead to significant variability on a variety of time scales.

- Calibrated five-year Earth Radiation Budget Experiment (ERBE) observations have documented that clouds have a net global radiative cooling effect on the Earth-atmosphere system by about 15 to 20 watts per square meter. The regional cloud forcing data have contributed significantly to diagnosing deficiencies in general-circulation model (GCM) treatment of cloud radiative interactions.

- Water vapor behavior and feedback analysis has been advanced on theoretical, observational, modeling, and methodological grounds.

- Understanding the role of volcanic eruptions as a climate forcing factor has been advanced, as evidenced by our ability to measure and examine the impact of recent eruptions (Mt. Pinatubo).

- The linkage of climate models with impact models on agriculture, water resources, ecosystems, and the economy, and quantification of the positive and negative effects of climate change and variability on agricultural production and water supply, have been substantially improved.

This research, however, has also underscored the complexities and uncertainties associated with detecting and projecting the nature of future climate change. For instance, a concern for anthropogenic global change cannot be dealt with in the absence of an adequate understanding and documentation of present and future climate and its natural variability on time scales of years to

centuries, as well as a quantified understanding of anthropogenic forcing itself. For anthropogenic forcing, we clearly need to determine the role of tropospheric aerosols and further elucidate of the carbon cycle.

Determination of the response to anthropogenic forcing is inseparable from understanding the natural system. This understanding ranges from solar and volcanic variability; to the feedbacks resulting from the interactions of water vapor, clouds, and radiation; to the massive heat fluxes associated with the motions of the air and oceans and the exchanges between them.

In short, changes in all the major factors that influence climate variability must be well described and their interactions understood. The evidence clearly shows that we must be able to couple the components of the Earth system, including the ocean, atmosphere, land, and ice, and describe major feedback processes in order to be able to reduce the uncertainties in describing the nature of future climate. The primary characteristics of the climate system must also be documented through consistent, long-term observations.

An understanding of both natural variability and anthropogenic global change is essential to address the wise use of resources, human health, agricultural productivity, and economic security. Improved global change predictions are central to these objectives and are key U.S. Global Change Research Program (USGCRP) research priorities. Addressing these complexities and uncertainties requires a comprehensive program. Each of the essential science elements listed below addresses uncertainties that currently hinder our ability to understand and predict future climate variability and change.

Essential Science Elements

1. USGCRP must characterize and determine the changes in the significant global change forcing factors (solar, carbon dioxide, other radiatively important gases, aerosols, land cover change) by means of continuous observation. Tropospheric aerosols are a major priority that have not been adequately addressed.

2. USGCRP must document global change (e.g., temperature, precipitation, ozone, air quality, ecosystems). Climate change requirements must be a part of current and future observational systems (including operational elements) and of satellite convergence efforts.

3. The identification and understanding of the natural variability of climate, including the historical and paleoclimatic record, must be a product of USGCRP efforts.

4. An ability to quantify the carbon cycle and its driving factors is essential for determining future atmospheric carbon dioxide levels.

5. USGCRP must have the combined observations, process studies, and modeling efforts necessary to address the issue of cloud-water vaporadiation feedback, which remains the major source of uncertainty in climate change predictions.

6. USGCRP efforts must be able to characterize the nature of the oceanic circulation, the surface fluxes of energy and moisture, and the ocean's natural variability.

7. USGCRP must have the combined observations, process studies, and modeling efforts necessary to address land-vegetation-atmosphere interactions.

8. It is essential to characterize and understand cryosphere (ice caps, sea ice, snow cover) responses to climate change.

9. USGCRP must include the basic science capabilities to address the impacts of global change on ecosystems, (e.g., forests and agriculture) and on water resources.

10. The critical economic, technological, and demographic trends that are affecting the ability of natural and human systems to cope with climate variability and change must be understood. These include changes in urban infrastructure, farming technologies, trade, and water use and efficiency--all of which can increase vulnerability or resilience to global change.

In reviewing the science elements above, all the major elements of the current program (e.g., Earth Observing System (EOS) measurement priorities, the National Oceanic and Atmospheric Administration (NOAA) climate research elements; the basic research components of the National Science Foundation; and the Department of Energy's ARM program) are essential. In fact, some of the elements (e.g., item 1,2,8, and 9 above) are currently not well addressed and must be enhanced. This must not occur at the expense of understanding basic features such as heat transfer by the oceans and atmosphere. There is little room for budget cuts in decade to century climate research without significant damage to critical science objectives. We, therefore, conclude that substantial budget reductions must come from other program elements, such as diverting savings from satellite convergence or increasing the efficiency of the EOS Data and Information System (EOSDIS). A multifaceted, balanced program that addresses each of these ten major science elements is essential so as not to have major gaps in our understanding that serve to limit both the utility of measurements and our predictive capability.

Issues of importance to the success of USGCRP are not restricted to addressing scientific priorities; a number of management issues, if addressed, would result in a stronger program. The field of global change research has had a history of significant progress and evolution involving integration of the essential components of research: data analysis, theory, and modeling. The maintenance and enhancement of progress demand a balanced approach. Intensive examination

of existing and future observations (in situ and remote), improved theory and modeling, the maintenance of existing and future measurements and calibrated monitoring, and the inclusion of climate considerations in the design of routine observations are required to satisfy crucial needs. Satellites offer unique capacity for global coverage and monitoring, and in situ measurements offer unique capacity for validation and for addressing critical details.

Essential Programmatic Changes

1. USGCRP must not be considered a collection of quasi-independent activities, although some independent efforts are necessary for creative opportunity. Nevertheless, the larger components must be managed as a set of serious scientific programs requiring continuous oversight, connectivity,and continuity across agencies; resource allocations and goals must be adjusted in light of developing knowledge and budget changes.

2. A scientifically and financially balanced program is essential, with strong components spanning in situ observations, satellite observations, process studies, and integrative modeling. The present management limits such balance.

3. The United States must enhance the linkages between national and international programs. However, the United States has become an untrustworthy international partner. Enhancement requires greater integration, which is difficult without stronger U.S. long-term commitment.

4. USGCRP must have the flexibility to include exploratory efforts. Part of the strength of a robust program involves opportunities for innovative inquiry by individual investigators and a capacity to address new issues.

E

ASSESSMENT OF NASA'S MISSION TO PLANET EARTH/EARTH OBSERVING SYSTEM (MTPE/EOS)

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WORKING GROUP SUMMARY

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EOS's program structure and science have been significantly improved. Its research is thoroughly peer reviewed by excellent, independent academic science teams with strong inputs from a wide range of respected scientists. The results of those reviews are routinely communicated to and acted on by the appropriate levels of the National Aeronautics and Space Administration (NASA) and the U.S. Global Change Research Program (USGCRP).

EOS provides unique information for the execution of required global assessments. Current sensors and platforms are appropriate and efficient. EOS sensors correctly reflect the Earth system science priorities that can be measured effectively with existing sensors and give proper emphasis to the development of sensors for other important phenomena. Areas in which change is needed are recognized and are being addressed. One is the need for properly documenting global change. Current sensors reflect an earlier emphasis on process studies. A rigorous dynamic calibration and validation program is essential for maintaining the dynamic continuity of critical long-term measurements through successive generations of sensors. Fortunately, EOS sensors are designed for high calibration.

EOS is properly configured for science and programmatic resilience. NASA has significantly increased opportunities for the introduction of advanced technology through experiments such as Lewis and Clark and through continuing science programs such as the Earth System Science Pathfinder (ESSP). It has become increasingly open to the infusion of technology from the Department of Defense (DoD) and industrial programs, which have significantly strengthened EOS.

Observing system priorities remain consistent with those of the USGCRP and the four MTPE science areas, which require ground and in situ measurements. Significant, rapid change has required and produced significant learning, but the broad, continuous EOS data sets remain relevant. The need for new measurements (e.g., tropospheric wind and aerosols, soil moisture) has become apparent and has stimulated productive thought on new means to measure them, perhaps from small satellites. It has also stimulated thought on new ways to perform key measurements such as lightweight synthetic aperture radars (SARs), hyperspectral sensors, and tropospheric chemistry sensors.

The current range of scientific uncertainties makes EOS's broad range of measurements relevant--particularly in that its sensors emphasize the validation, calibration, and continuity required for the detection of subtle climate signals. EOS supports a wide variety of societally relevant assessment programs and applications such as deforestation, agriculture, and water resources and quality. It addresses these priorities in cooperation with ground-based and in situ sensors. Current efforts include a productive mix of space, in situ, and ground measurements through a proper blend of agency contributions. The detailed correlation of space sensor capabilities with current science area priorities could be usefully addressed by a longer study.

Technological opportunities are being pursued aggressively. There is a sound process for the design of sensors with the performance and calibration required for measurements of the quality required for global change research. That process proceeds from requirements, through technology and trades, to sensor designs, in which size is properly seen as a dependent variable. EOS sensors use best current technologies and calibration methods--including those of DoD--to optimize performance. EOS is now the principal driver of sensor technology and research. Although it is fairly new and not fully activated, there is now a process for the incorporation of other emerging technologies, as well as established vehicles for the importation of technologies developed for other purposes by DoD and industry. There is adequate launch capability in existence or development for satellites of all sizes. All are affordable, although the cost per kilogram of payload is about a factor of three higher for small launchers than for launchers in the Delta class, as is designing spacecraft for compatibility with several launch vehicles to reduce sensitivity to launch losses at modest cost and performance penalties.

We can now build capable satellites of any desired size effectively; their performance domains are evolving rapidly. We now understand better when it is possible and appropriate to distribute sensors over many satellites. It is also better understood when various technologies should be used (e.g., technologies developed by DoD appear applicable to laser aerosol measurements, but not to spectral measurements, for which they currently lack calibration). It is also understood how efforts such as the New Millennium Program (NMP) can address bus costs, but not usefully substitute for operational buses or reduce system costs, which NMP does not address.

Small satellites promise low spacecraft costs and short schedules--typically one to two years from conception to flight. They provide mission and programmatic flexibility, which are important in stimulating innovation. Formation flying may also enable their use in replacing failed instruments or in maintaining dynamic continuity of measurements when introducing new sensors. Small satellites are currently best suited for focused missions of narrow scope. They are not universally applicable to the current generation of EOS sensors, many of which are too heavy or too large for small satellites. Life-cycle costs (sensors, satellites, launch, mission operations, and data acquisition) are not necessarily reduced by replacing the current multisensor medium-sized satellites with many small satellites for the deployment of a full suite of high-quality, calibrated sensors. Advances in technology, such as may come from the ESSP, NMP, and other sources, might alter this conclusion within the next few decades.

Data continuity is essential for meaningful scientific results. Space programs such as NASA's Landsat have successfully produced long-term records of key parameters, although not with the calibration desired by the climate research community. EOS will fly well-calibrated radiation, tropospheric water vapor, and aerosol sensors, as well as a series of Moderate Resolution Imaging Spectroradiometer (MODIS) instruments for the cloud feedback studies suggested by the Marshall Institute and others. As the latter have, long-term programmatic stability is essential for the success of these studies. To extend the studies of physical climate effects to global change, which is more complex, requires measurements over oceans and land--

hence their inclusion in EOS. It is unlikely that a narrowly focused study would provide satisfactory long-term answers to these questions.

Convergence opportunities offer the promise of reduced overlap, reduced cost, and improved science through NASA, National Oceanic and Atmospheric Administration (NOAA), and DoD cooperation on weather and climate satellites. There are significant institutional barriers and technical issues that could impede such convergence, but the payoff is so great that it justifies extensive study. If operational instruments were calibrated to research standards, a wide community of users would benefit. Much the same can be said for multiuse (science, operational, military, commercial, and international) missions on common platforms. Such developments have been strongly resisted because of cost, interference, and regulatory concerns, although these arguments are becoming less relevant while the potential savings are increasing.

There is a long, successful history of international cooperation in Earth observation. Many nations are providing satellites and sensors that form an essential part of the MTPE program. European and Japanese sensors will fly on NASA satellites and vice versa. Data exchange agreements are being implemented among these partners and others to maximize their value to the overall community. Many of EOS's sensors are provided by international partners; they are coordinated through EOS-ESA (European Space Agency) sensor discussions; and Europe, Japan, and Canada will provide EOS ground segments. In operational systems, NOAA polar orbiters carry important donated foreign instruments, and Europe's EUMETSAT will assume responsibility for one of NOAA's traditional satellite flights near the turn of the century. When one of the U.S. Geostationary Operational Environmental Satellite (GOES) geostationary weather satellites failed, EUMETSAT provided one of its satellites to prevent data loss for the critical Atlantic seaboard.

These international arrangements are voluntary and exercised primarily through the Committee on Earth Observation Satellites (CEOS). Reliance on such mechanisms leaves the United States with no fall-back position in the event of default, although U.S. reliability has been most in question of late because of issues such as Topex-Poseidon. It would be useful to isolate EOS from current political issues. At present, the United States has limited ability to affect these arrangements because of the inability to make multiyear commitments. There could be significant benefits from being able to address reliability by entering into multiyear commitments on satellites, sensors, and global observing systems.

Innovative approaches to data collection and management may offer significant savings. Data purchases still appear attractive and useful, despite recent experiences with SeaWIFS. However, the government would have to enter into long-term contracts to stabilize purchases sufficiently to secure the interest of industry. Commercial activities and opportunities for sensors on commercial constellations such as Teledesic and IRIDIUM are uncertain. There has been only limited contact and discussion, and industry reception to date has been characterized as not very positive. That is understandable. The market is very uncertain. Only the upper limit of the estimates of its magnitude would approach the cash flows involved in those systems; anything less would be viewed as a hindrance to their rapid deployment. In any case, communication satellites

do not use polar sun-synchronous orbits; the radiometric correction of data taken from their orbits does not appear feasible.

Applications of EOS data are much greater than those of previous Earth sensing satellites. For agriculture, Landsat-7 offers a major improvement in the measurement of crops, and the AM and PM (morning and afternoon equator crossing) platforms will significantly improve measurements of vegetation and moisture. For land use, Landsat-7 will greatly improve surveys of biodiversity, and AM will improve the precision of maps. For seismology, AM will document changes in land surface and volcanism. For hydrology, radars will improve topography and El Niño/Southern Oscillation measurements; lasers will measure ice; and AM and PM will significantly improve understanding of cloud dynamics and cover. For mapping, AM will provide digital elevation; lasers will give ice and land elevation. For national security, Landsat-7 will greatly improve the type of global surveillance provided for the Gulf War; AM will improve map resolution; and PM will give the moisture measurements needed for force mobility analyses. All of these improvements will be of significance for both civil and commercial applications.

Program Impact Issues

Restructuring has protected the EOS program and increased its resilience, but that process has reached its limit. Significant reductions in annual or aggregate budgets or imposed constraints on technical options could result in elimination of key sensors or platforms, slippage of schedules, loss of continuity in data sets, or elimination of the mechanisms for promoting the innovation needed for downstream cost reductions and science improvements. A premature shift to small platforms could eliminate key measurements.

Summary

EOS's science and program are valuable, unique, and resilient. It would be appropriate to reduce its reviews to regular but less frequent intervals. Its space observation program has appropriate balance internally, but needs to be balanced with ground and in situ measurement across all of the USGCRP priorities. EOS priorities are evolving and open to technological innovation. Its sensors are well designed and calibrated. Given long-term program stability, they should be able to provide the quality of continuous measurements of radiation, vapor, aerosol, and cloud feedback necessary to understand and document climate change.

EOS is open to the introduction of technology from research, DoD, and commerce. Adequate launch and fabrication capability exists for satellites of all sizes. Small satellites offer flexibility and rapid innovation--at a penalty in cost. However, it should be possible to use them effectively to perform rapid tests of new sensors for key parameters such as tropospheric winds, aerosols, and soil moisture, among others.

Convergence offers significant advantages and savings domestically and internationally. Impediments to the convergence of domestic programs, which are largely institutional, could profit from more careful study and definition. International collaboration has a long, successful history. Current impediments, which are produced in part by the voluntary nature of these collaborations, could be improved by multiyear commitments. EOS data will have significantly greater value for civil, commercial, and defense applications than the data from previous lower-resolution sensors. These applications alone could justify maintaining EOS's schedule. However, although the EOS program remains resilient, it is now stretched to its limits. Further reductions or constraints could reduce its technical capabilities and delay or eliminate those advances.

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THE EARTH SCIENCES INFORMATION SYSTEM

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WORKING GROUP SUMMARY

John A. Dutton, *Chairman*

The Earth Observing System Data and Information System (EOSDIS) is a central component of the EOS program for linking observations made from space with those obtained on the ground and assisting scientists to convert them into enhanced understanding of the Earth system and the processes that drive its evolution. EOSDIS must be designed and implemented so that the investment in EOS space observations is multiplied many times through revealing analyses, through new models of the Earth system and its components, and through stimulation of a wide range of educational and economic activities. The EOS program, and indeed the entire U.S. Global Change Research Program (USGCRP), cannot be successful unless EOSDIS fulfills expectations that it will empower new levels of achievement in the Earth sciences and applications, and in a wide range of activities in both the public and the private sectors.

To meet these expectations, we must now embrace a revolutionary expansion of the conceptual model that governs the management and operation of the system by affording the scientific community full partnership with shared responsibility. If we create and commit ourselves to the right model, all of the details related to design and technology will fall into place readily. Moreover, a new and successful model for EOSDIS, and by extension for USGCRP as a whole, will provide a stimulus for new approaches to data and information management in a wide variety of activities and will broadly benefit the nation.

The two key requirements for the system are that it must

1. utilize an open management approach in which key decisions are made with community leadership, and assignment of responsibilities is based on peer review; and

2. encourage innovation and creativity through wide participation of the scientific, public, and private sectors.

The revolution proposed in the management and implementation of EOSDIS will prove successful only if it incorporates, from the beginning, powerful incentives and meaningful criteria. As criteria for evaluating the design and implementation, that the new concept should ensure that

- users can readily locate data sets with real and valuable scientific content;

- users can access and utilize such data sets readily and in a timely fashion;

- collaborative analysis and research is stimulated and encouraged; and

- demonstrable progress in scientific endeavors and in applications to other activities is evident.

To provide incentives for the scientific community, the system must enable and encourage scientists and scientific teams to use it for interaction and as a form of electronic publication and dissemination of their results.

Historical Background of EOSDIS

The EOSDIS was conceived a decade ago by the science steering groups that developed the initial plans for EOS as a powerful, distributed data and information system that would provide ready access to the data and stimulate new levels of scientific creativity and collaboration in studying the wide range of interdisciplinary issues that must be resolved to understand the evolution of the Earth system.

However, the system design developed in good faith by the National Aeronautics and Space Administration (NASA) was shaped and constrained by the engineering protocols then in vogue for the development of large and complex hardware systems. Thus, the initial architecture proposed by NASA was to be centrally controlled and operated to ensure that it met ambitious performance and reliability requirements. Later versions developed in response to the objections and advice of the scientific community retained these features. The architecture required by NASA in the initial contract with Hughes Applied Information Systems (HAIS) generated considerable concern and was revised after a thorough National Research Council (NRC), 1994 review that produced recommendations for a logically distributed system, based on a client-server model, that would accommodate evolving computer system concepts and technology. Despite the notable improvements in architecture and concept introduced by HAIS in response to NRC recommendations, the current design and performance requirements, the system of multiple Distributed Active Archive Centers (DAACs) (each configured as a stand-alone, high-performance, and highly reliable computing center), and an extensive engineering and management superstructure are stressing the bounds of affordability (see Table 1).

Still, considerable progress has been made. This new client-server architecture of EOSDIS takes advantage of logical distribution and modularity and will allow the system to evolve as both computer system concepts and technology advance in the years ahead. The system now can take advantage of the concepts of the World Wide Web (WWW), the continuing advances in computer and storage capabilities, and the advantages conferred by developing a set of permissive standards appropriate to global change research that will enable and encourage wide access to EOSDIS and wide use of, and contribution to, its resources. Thus, with appropriate incentives, the system can be flexible and quick to adapt to a rapidly changing environment.

TABLE 1.1 EOSDIS Components and Costs (FY 1991-2000)--NASA Concept

Components	Cost ($ million)
Flight and Data Operations	
Flight operations and spacecraft control	86
Ground stations (communication with spacecraft)	50
EOS data and operations system (data capture and initial processing)	225
EOSDIS backbone network (transmit data to DAACs)	106
Distributed active archive centers (preparation of data products)	1,021
Distribution of data to users via Internet	52
System Engineering and Management	
System engineering and integration	372
Program and project management	74
Related science support	144
TOTAL	2,230

A New Concept: The Earth Sciences Information System

The present plans for the development of EOSDIS have been widely criticized for reasons ranging from an apparently excessive cost to lack of a governance structure that engages and empowers the scientific community. A number of observers do not believe that problems with the system can be eliminated by engineering redesign. Instead, the concerns are much more fundamental and are related to the basic management approach--to the conceptual model that has guided and constrained the management and engineering of EOSDIS.

Thus, a new model is proposed that will distribute many of the functions of the system to a wide range of government, academic, and private organizations through a competitive process. To distinguish this new model from those of the past, will be referred to it as the Earth Sciences Information System (ESIS). The basic concept is illustrated in Figure F-1. The functions shown

FIGURE F-1 Earth Sciences Information System

on the left--flight control, data receipt and Level-0[1] archive, and initial processing of the of the data through Level 1--will follow the existing EOSDIS model. Although the model for this part of the system does not change, that these functions can be streamlined considerably with important reductions in cost.

On the right, the generation of products and the combination of initial products into a wide range of scientific data fields would be opened to a competitive process through an Announcement of Opportunity, with bidders allowed to bid on any number and combination of products and services. It may be anticipated that the successful bidders will include NASA laboratories (perhaps some of the present DAACs), teams of EOS investigators, other academic collaborators, and private sector organizations and firms. These entities are referred to as NASA Earth Science Information Partners (ESIP) and it is anticipated that similar organizations will develop outside of NASA sponsorship or supervision. Thus, ESIS will become a privatized, market-driven federation of product generation and enhancement capabilities. Rather than a centrally managed entity, it will become a coordinated activity, drawing in new participants.

The effectiveness of NASA ESIPs will be determined by the criteria used to evaluate both proposals and continuing performance. Three are recommended:

1. timely production of specific scientifically meaningful products;

2. provision of effective user support and appropriate data access; and

3. formatting data sets and associated documentation in a form suitable for transmission to permanent libraries.

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[1] Definitions of Data Levels (Adapted from the MTPE EOS Reference Handbook, NASA/Goddard Space Flight Center, 1995)

Level-0 - Reconstructed, unprocessed instrument data at full resolution

Level-1A - Level-0 data with ancillary information including time, geo-location, and calibration coefficients.

Level-1B - Level-1A data processed to sensor units (if applicable)

Level-2 - Derived geophysical variables at the same resolution and location as Level-1 source data

Level-3 - Variables mapped on uniform space-time grids, usually with some completeness and consistency

Level-4 - Model output or results from analyses of lower level data, including variables derived from two or more measurement

Introducing competition will have important consequences. The first is that bid prices will be consistent with the marginal cost of providing actual ESIS services and thus can be presumed to be considerably less than the cost of dedicated, stand-alone facilities. Second, the new model is intellectually inclusive and will attract new participants, creating a much broader and more effective process for attacking the key problems of global change research. Third, with the development of standards and protocols to interchange data sets on Internet and WWW, ESIS will create a new capability of broad value to the scientific community and the private sector and thus to the entire nation.

With suitable extensions of the catalogs and advertising services being developed by HAIS, the results of EOS research will be available to all Internet users. This, too, has important consequences. First, with appropriate standards, a wide range of scientists and scientific facilities that use EOS data will be encouraged to make their results available to others by conforming to system standards and thus publishing them electronically. Second, a market for ESIS services will develop in which value-added concerns will offer search, browse, and data delivery services that are extensions of the basic capabilities. Such services may be especially attractive to private sector users of EOS results and to schools and colleges.

Issues, Challenges, and Risks

The most evident logical difference in the two models is that responsibility for processing and product generation at Levels 3 and higher has been transferred from designated government facilities to the federation of community entities. In this section, we provide a preliminary view of some of the consequences is provided.

A variety of issues and risks are common to all computer systems and all endeavors in scientific data management. These include archiving, security, providing user assistance, and documenting user activities. Preliminary study, leads to the conclusion that, except for minor variations, these are essentially similar in the two models. Successful bidders will have to demonstrate that they understand these issues and have adequate and rigorous plans for dealing with them.

The proposed model for ESIS does pose new issues, however. The first is that of managing collaboration in a competitive environment. Developing, processing, maintaining, and improving EOS scientific products will require collaboration between the instrument teams or investigators. Moreover, the strong interdependencies of some data sets will mandate effective collaboration and careful scheduling. The Announcement of Opportunity must provide for arrangements that will encourage the necessary collaboration and include initial provisions or a negotiation phase to permit instrument teams to explore collaboration with several bidders or an otherwise successful bidder.

Moreover, even in the proposed decentralized and federated systems, a number of specific functions will require centralized intellectual leadership, an example being definition of standards

for metadata and supporting documentation. Further elaboration of these should take place in later stages of this review.

A second and critical issue is the governance of the new ESIS system. A significant advantage of the proposed model is its potential to stimulate the collaboration and wide participation of the scientific community in the processing and refinement of EOS products and in the development of higher-order products that reveal new aspects of an improving scientific understanding of the Earth system. To achieve this potential, the system must be responsive to users and participants--it cannot be centrally managed from the top down but must be governed as a federation of collaborating entities. Moreover, the federation must expand to include other agencies and the research teams they support. A 1995 NRC report sets forth the basic structure of such a federation in the context of managing scientific data (NRC, 1995).

A third issue is that the transition to the new system must be very sensitive to the expectations of international partners and the commitments that have been made to them. Agreements in place must not be jeopardized and should be modified only with the enthusiastic concurrence of these partners, many of whom may prefer ESIS capabilities to the present plan.

A fourth issue is whether reassessment and relaxation of system performance and reliability requirements will produce significant savings in total costs. Current requirements derive from the spacecraft data production rates and are designed to reduce risks to the central facility. With adoption of the ESIS model, the risks are transformed into those associated with scientific research, and tolerance for central risk can be increased. For data products deriving from the AM-1 platform, the transition will have to be handled with particular care because of complex interdependencies and tight schedules.

Finally, the success of either model depends in part on the continued viability of the Internet as a mechanism for high-bandwidth computer-to-computer communication. Bidders would have to demonstrate the commitment of their host organizations to maintain Internet connections of sufficient bandwidth. Although the advancing capabilities of the Internet or other national high-performance computer communication capabilities are expected to keep pace with demands for service, there is a risk that they may not. A first complication would be inadequate bandwidth to support the interactive processing of interdependent products; such a difficulty could be ameliorated by transfer of data on physical media via overnight delivery. A second complication would be charges for Internet services, a development that would lead to complications for scientific research that extend far beyond EOS. Such complications would be equally problematic in both models.

Transition to the New Model

The ESIS model will create a data and information system that operates differently from the present concept and will require that the transition be carefully managed. The most important action now is to adopt the new intellectual concept for the system and be clear about our long-term

goals. Every attempt should be made to put as much of the new system as possible in place before the launch of EOS AM-1. To do so, NASA, EOS investigators, and EOSDIS contractors must begin immediately to conduct a collaborative study of the implementation and cost of the federated system and to develop a plan for an effective, streamlined central management and engineering capability. Some representative actions typical of those required in such a study are listed in the next section. Although such a study may demonstrate that a gradual or incremental transition to the new system is advisable, we argue that the initial effort should be directed toward effecting a dramatic break with the past and creating an entirely new and contemporary federated management and operation of ESIS.

Recommendations

The following two recommendations summarize the discussion in this appendix:

Recommendation 1

- The components of the EOSDIS now under development for flight control, data downlink, and initial processing should be retained, but streamlined.

Representative Actions to Respond to Recommendation 1

1. Assess rigorously the relative costs of transmitting and receiving EOS spacecraft data with and without the Tracking Data Relay Satellite System (TDRSS).

2. Reevaluate EOS Data and Operations System (EDOS) functions with the aim of incorporating advanced technologies and limiting the scope to that needed for data capture and processing to Level-0. Reduce initial data processing costs by utilizing receiving stations for Level-0 processing and existing capacity at DAACs (e.g., at Goddard and EROS Data Center) for Level-0 to Level-1 or Level-2 processing.

3. Explore with end-to-end system plans the use of advanced technologies and concepts such as solid-state spacecraft data recorders, increased spacecraft autonomy, and contemporary data packet protocols to simplify data operations and reduce overall costs.

4. Explore replacement of the EOSDIS Backbone Network with commercial facilities to reduce engineering and continuing management costs.

5. Evaluate possible advantages and relative short-term and long-term cost savings

associated with development of a unique flight operations system for each mission in order to take maximum advantage of new capabilities, new technologies, and lessons learned from previous missions.

Recommendation 2

- Responsibility for product generation and publication and for user services should be transferred to a federation of partners selected through a competitive process open to all.

- To effect this recommendation, it will be necessary to examine the systems implications of reconfiguring EOSDIS as a loosely-coupled federation of quasi-autonomous partner organizations, each with a contractual obligation to perform a subset of the tasks involved in preparing and distributing scientifically reliable products at Level-2 and higher, identifying in particular those functions or services to the federation that must be provided centrally and those for which responsibility can be delegated to the partners.

Representative Actions to Respond to Recommendation 2

1. Reassess schedule, continuity, and reliability requirements for standard data products with the aim of simplifying preparation of the scientific data products, and thus reducing costs. Examine with EOS investigators and other potential users the hypothesis that only Level-0 data must be treated in a rigorous production sense.

2. Assess rigorously the advantages, disadvantages, and relative costs of moving Level-1 or Level-2 data to a distributed system of scientific data processing partners via Internet, commercial surface and space-based communication networks, or overnight delivery of media.

3. Obtain (from EOS instrument Principal Investigators and teams, other investigators, and an appropriate subset of existing DAACs) realistic cost estimates for preparing representative scientific data products in distributed processing units.

4. Develop prototype models of minimum machine-independent data format standards and interchange protocols that will facilitate exchange, interactive use, and electronic publication of EOS scientific data sets over existing commercial and Internet facilities. This effort should engage experts from the academic and commercial computer science communities and should concentrate on whether extensions to existing standards, such as those used on Internet and World Wide Web, are necessary or advisable.

5. Develop prototype protocols for peer review and signed electronic publication of scientific data sets that would provide incentives and quality control motivations to producers of these data sets.

6. Explore the use of information search facilities modeled on those now in use on the World Wide Web as a means of providing users with data search and access capabilities; explore whether the EOSDIS Version 1 and Version 2 systems could operate exclusively over the Internet (or anticipated national high-performance computer communications networks) to facilitate data exchange by scientists and to provide search and access capabilities to users.

7. Explore possible advantages of dividing EOS data into categories in order to determine the most effective means of processing and distributing data to users. Possible categories (and possible data producers) include operational data for other agencies (many possible producers, depending on timeliness), data of use to a limited community of scientists (instrument teams or Principal Investigators), data of wider scientific use (many possible producers), data of interest to educational institutions and the public (scientific or commercial data facilities), and data with commercial value (commercial or academic bidders).

8. Develop a preliminary model of a procurement process and an Announcement of Opportunity that could be used to solicit proposals from potential participants in a distributed scientific data processing system.

9. Develop a plan and realistic cost estimates, using the information generated by the above actions, for a distributed data processing federation as envisioned in Figure F-1, and seek the comments and advice of EOS investigators and the broader scientific and other user communities.

CONCLUSION

The proposal made here for creating ESIS offers many advantages to the government and the scientific community. Rather than being managed top-down by the government, the new model will create a federation of participants. By taking advantage of Internet capabilities, it will extend access to EOS results to a wide audience, including new participants in the private sector. Although substantial savings may be expected, the costs of the new approach can be estimated only after careful study.

Most significantly, it will stimulate participation of the scientific community in the governance of ESIS and create an entirely new system that can be the model and foundation for

the broader Global Change Data and Information System. Perhaps its greatest benefit, however, will be that it will generate a new approach to the interactive management and use of distributed data sets and, with an appropriate set of standards and protocols, provide a new capability of significant benefit to a nation increasingly dependent on collaborative and innovative exploitation of complex arrays of data and information.

The proposed new approach has substantial benefits and some challenging risks. However, the benefits envisioned more than compensate for those risks.

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Chairman WALKER. Thank you very much. We appreciate your testimony. We will now move to Mr. Brad Hathaway from the U.S. General Accounting Office. Mr. Hathaway?

Mr. Hathaway?

STATEMENT OF MR. BRAD HATHAWAY, U.S. GENERAL ACCOUNTING OFFICE, WASHINGTON, DC.

Mr. HATHAWAY. Mr. Chairman, it's an honor to be here today to discuss the previous work that we at GAO have done on the lifecycle cost of EOS, and our ongoing work on the research community to analyze EOS data.

We reported, and you mentioned in your opening statement, Mr. Chairman last June, that the life cycle of the baseline EOS program at that time would be about $33 billion.

We'll report further to you on the cost reduction efforts after the release of the Fiscal Year '97 budget when we get a chance to review the data and the submission from that.

The preliminary results of our ongoing work into the research community for analyzing EOS data is that we believe that NASA's current EOS basic research community is relatively small compared to pre-EOS missions, and it's uncertain whether NASA can successfully expand it within future budget constraints.

If NASA is not successful, there might be an imbalance between investigations and the EOS data.

Let me discuss costs a little bit first.

Initial planning for EOS, as you know, occurred during the 1980s, when NASA's budget was increasing each year. In 1991, NASA's plan for spending on EOS was $17 billion through the year 2000.

In 1992, we reported on a growing gap between NASA's program plans and its probable future budgets. Congressional concerns about EOS's affordability caused NASA to change EOS's focus to global change on the earth's climate.

This estimated cost through the year 2000 was reduced to $11 billion and then to $8 billion and then to $7.25 billion.

Over the last several years, NASA was successful in closing the affordability gap that we had identified. However, by the President's 1996 budget submission, that gap had reopened. Although much of the budget debate focused on that first decade of the program, EOS is planned to continue for another 20 years beyond that.

In June, as I said, we reported life cycle cost estimates for the then-EOS baseline program, totalling about $33 billion from Fiscal Year '91 through Fiscal Year 2022.

NASA recognized that the program, as designed in early 1995, was not affordable. It was already studying ways to substantially reduce costs. They continued that effort, and I believe you'll be hearing more about that later on this morning.

Let me turn to NASA's strategy to build an EOS research community.

NASA originally solicited proposals for EOS interdisciplinary science investigations in 1988 and selected 29 teams.

In our ongoing work, we found that although NASA has not determined what size research community is sufficient, last year it

recognized that more basic research teams were needed. NASA solicited proposals in September, to address specific interdisciplinary science issues that are not well covered by existing investigations. However, the announcement largely precluded investigators from analyzing data from EOS missions. Instead, NASA asked for them to propose research that primarily uses existing data sets.

NASA intends to support this research by freezing the budgets of some of EOS's interdisciplinary science investigations.

EOS's 29 teams needs to be put in context.

Over the years, NASA has stated that about 10,000 earth scientists might use EOS data. However, we found that for this type of work, scientists generally analyze data when they are paid to analyze data.

We reviewed 172 journal articles about two pre-EOS earth science missions—the Upper Atmosphere Research Satellite, UARS, and the TOPEX/Poseidon. Publicly-funded investigators wrote all but ten of those articles.

Our observation that the size of the EOS research community is relatively small is based on a comparison with the number of science teams associated with those two missions and the ratio of the number of science teams to the raw data acquisition rates.

UARS consists of ten instruments that are measuring the composition and temperature of the upper atmosphere, atmospheric winds and energy from the sun.

In the EOS era, solar energy and atmospheric chemistry measurements will be made principally by three instruments and the CHEM spacecraft. Currently, only 12 instrument and interdisciplinary science teams are associated with these instruments and the CHEM spacecraft.

In contrast, UARS research is conducted by 62 teams.

TOPEX studies the circulation of the world's oceans. NASA and its French partner selected 38 science teams.

In the EOS era, the follow-on mission to TOPEX is Radar-ALT, and although an instrument team hasn't yet been selected, only 7 of the 29 inter-disciplinary science teams currently plan to use Radar-ALT data in their investigations.

Now there's a striking difference between the number of science teams and the volume of data for pre-EOS missions and EOS.

Taken together, the number, but not necessarily the size, of the UARS and TOPEX science teams is a little larger than all of the EOS teams, while EOS's data rate is close to a thousand times greater than the combined data rate of UARS and TOPEX.

Now although we recognize that the data rate comparison is at best a rough gauge, the difference is too large to ignore.

Achieving the best science return on the large investment in EOS will require a proper balancing of space systems, information systems and researchers. It's not clear to us that NASA will achieve this balance because the science community, funded to do basic research under EOS, is relatively small, and although NASA recognizes the need to increase the number of basic researchers, we remain concerned about NASA's ability to fund more basic research through future savings that may not materialize or that may be absorbed by budget reductions.

That completes my statement, Mr. Chairman.

[The prepared statement of Mr. Hathaway follows:]

United States General Accounting Office

GAO

Testimony

Before the Committee on Science, House of Representatives

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EARTH OBSERVING SYSTEM

Cost and Research Issues

Statement of Brad Hathaway, Associate Director, Defense Management Issues, National Security and International Affairs Division

GAO/T-NSIAD-96-116

Mr. Chairman and Members of the Committee:

I appreciate the opportunity to testify before the Committee today on the National Aeronautics and Space Administration's (NASA) Earth Observing System (EOS). You asked us to discuss (1) our previous work for the Committee on the investment that will be required over the life of EOS and (2) our ongoing work on NASA's strategy for maximizing the science return on that investment by ensuring that an adequate research community will be available to analyze the large amount of data expected from EOS.

We reported to you last June that the estimated funding requirements of the baseline program would total about $33 billion over the life of the program.[1] Because of its constrained budget outlook, NASA had already begun looking for ways to reduce future EOS funding requirements. We will report to the Committee on NASA's cost-reduction efforts later this year, after we have reviewed NASA's latest funding estimates, which will be released later this month with the fiscal year 1997 budget submission.

A preliminary result of our ongoing work is that NASA's current EOS basic research community is relatively small compared to other pre-EOS earth science missions, and it is uncertain whether NASA can successfully expand it within future budget constraints. If

[1]That is, for fiscal years 1991 to 2022. As planned in 1995, the last EOS satellite will cease operations in 2020, after which there will be 2 years of data analysis. See NASA'S Earth Observing System: Estimated Funding Requirements (GAO/NSIAD-95-175, June 9, 1995).

NASA is not successful, there may be a growing imbalance between the number of funded investigations and the magnitude of the potential research opportunities created by data from EOS' instruments. This imbalance in EOS could limit the number of funded investigations designed to produce the best possible science return on such a large investment.

BACKGROUND

EOS is the centerpiece of Mission to Planet Earth, NASA's contribution to the governmentwide U.S. Global Change Research Program. EOS-related funding accounted for about $1 billion of the $1.3 billion total budget for Mission to Planet Earth that the Clinton administration requested for fiscal year 1996. EOS has three major components: (1) a system of satellites to collect at least 15 years of key climate-related data; (2) a data and information system to operate the satellites and process, archive, and distribute the data; and (3) teams of scientists to develop algorithms for converting sensor data into useful information and conduct research using the information.

EOS is currently designed to make 24 types of long-term measurements of solar irradiance and the earth's atmosphere, land cover, ice sheets, and oceans from orbiting spacecraft. According to NASA, these measurements are essential to detect, understand, model, and predict global climate change. The first EOS satellite is scheduled for launch in 1998. By 2002, when the full constellation will be in orbit, EOS will be generating data

from 25 instruments on at least 10 spacecraft. Over the 20-year EOS data-collection phase, about 80 instruments will be launched on more than 30 satellites. See attachment I for the EOS instrument flight schedule.

Initial planning for EOS occurred during the 1980s, when NASA's budget was growing steadily. During this time, NASA's funding increased each year, essentially doubling from about $5 billion to $10 billion between fiscal years 1981 and 1989. In anticipation of continued budget increases, NASA planned to spend $17 billion on EOS through fiscal year 2000 when the program was initiated in fiscal year 1991. However, it soon became clear that NASA's budget would not increase as originally planned. In 1992, we reported on a growing gap between NASA's program plans and its future budgets that would likely be far lower than originally anticipated.[2]

Congressional concerns about EOS' affordability caused NASA to change the program's emphasis in fiscal year 1992 from a complete earth system measuring program that would have supported a wide array of global change investigations to a measurement program that will primarily support investigations of global changes to the earth's climate.[3] EOS was redesigned, and the estimated cost through 2000 was reduced to $11 billion. The program's budget through 2000 was further reduced to $8 billion in fiscal year 1993, and

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[2]NASA Budget: Potential Shortfalls in Funding NASA's 5-Year Plan (GAO/T-NSIAD-92-18, Mar. 17, 1992).

[3]For example, NASA dropped the measurement of mesospheric and ionospheric chemistry and solid earth processes.

to $7.25 billion in fiscal year 1995. Through reductions in EOS funding and other programs over the last several years, NASA was successful in closing the affordability gap we reported on in 1992. However, substantially reduced outyear projections in the President's 1996 budget submission reopened the gap, requiring NASA to examine ways to reduce the cost of its programs and activities.[4]

EOS TOTAL LIFE-CYCLE COST

Although many of the past EOS budget discussions focused on the first decade of the program, EOS is planned to continue for another 20 years beyond that. At the Committee's request, we reviewed the total life-cycle cost of EOS. In June 1995, we reported to you that the estimated funding requirements of the EOS baseline program would total about $33 billion for fiscal years 1991 to 2022.[5] This estimate was developed for the program as described in NASA's 1995 EOS reference handbook, and included costs for satellites, launch services, data systems, science, construction of facilities, and civil service personnel. NASA recognized that the program as designed in early 1995 was not affordable in an environment of declining budgets and was already studying ways to substantially lower future program costs through the use of advanced technology and increased collaboration with other agencies, international partners, and the commercial

[4]NASA Budgets: Gap Between Funding Requirements and Projected Budgets Has Been Reopened (GAO/NSIAD-95-155BR, May 12, 1995).

[5]This figure is in current dollars and includes future years' inflation.

sector. NASA intended to apply these future savings to increasing the science supported under EOS and Mission to Planet Earth and to reducing the total cost of the program.

NASA'S STRATEGY TO BUILD AN EOS RESEARCH COMMUNITY

Like EOS-related space systems and information systems, the development of the EOS science community that will conduct EOS research will not just happen; it has to be developed. NASA recognizes that it needs to increase the size and broaden the membership of its EOS science teams and take other steps to develop and sustain an EOS-era research community. In 1995 and 1996, it began adding new investigators and reevaluating the current EOS science teams' investigations. NASA's success in adding investigators however, is uncertain within its expected future budgets, especially if the development of the EOS science community depends on realizing future savings in the program.

NASA's strategy involves (1) an open data access policy and (2) efforts to expand and change the current EOS research community by adding investigations, reevaluating the current science investigations, and recruiting new investigators.

EOS Data Policy

A vital part of the EOS data policy is that EOS data will be available to everyone: there will be no period of exclusive access for funded investigators. This has not always been NASA's policy. On some past earth observing missions, funded investigators had exclusive use of the data for an extended period of time.[6] EOS data users as a rule will not be charged more than the cost of distributing data to them. The data policy contemplates a variety of potential user groups, not all of whom will be engaged in basic research. Last year, NASA sponsored a conference that tried to better define the user groups. The conferees identified 12 potential user groups, of which only 3 were primarily composed of scientists. The others included commercial users, resource planners, and educational groups.

Adding Investigations

NASA originally solicited proposals for EOS interdisciplinary science investigations in 1988 and selected 29 interdisciplinary science teams in 1989 and 1990, with other selections possible before the launch of the first EOS satellite, then scheduled for late 1995. The lifetime of the first group was to extend for 4 years beyond the launch of the

[6]For example, the original investigators associated with the Upper Atmosphere Research Satellite had exclusive access to the first year's data for up to 2 years.

first satellite, or until 1999. In short, NASA intended to fund more than one group of investigators over a 10-year period (1989 to 1999). These intentions were stated within the context of expanding resources through the 1980s. Soon after, NASA's budgets stopped growing, and, as a result, the number of science teams has remained the same and their tenure has increased. At a minimum, the lifetime of the first group of investigators has been extended to 13 years (1989 to 2002), including 4 years beyond AM-1's 1998 launch date.

EOS science investigators were selected to (1) analyze and interpret data from EOS instruments in more than one earth science discipline and (2) serve as members of the Investigator Working Group, developing detailed science plans and assisting NASA in optimizing the scientific return of the EOS mission. Currently, there are 31 interdisciplinary principal investigators, 9 of whom are affiliated with foreign agencies and/or institutions. NASA is wholly or partly funding 22 investigations, and its international partners are funding 7. There are also 354 coinvestigators associated with the 29 interdisciplinary science investigations as well as 20 instrument principal investigators/team leaders and 197 other instrument team members.

In our ongoing work, we found that although NASA has not determined what size research community is sufficient to meet EOS' basic research goals, last year it recognized that more basic research teams were needed, and took a limited step to expand the community. NASA solicited proposals in September 1995 to address specific

interdisciplinary science issues that are not well covered by existing NASA-funded investigations.[7] However, the announcement largely precluded investigators from analyzing data from the first EOS mission, AM-1, which is now scheduled for launch in 1998. Instead, NASA asked them to propose interdisciplinary research that primarily uses existing data sets from past satellite missions and field experiments. NASA received 134 proposals for interdisciplinary science investigations and expects to fund 20 to 25 investigators. NASA intends to solicit additional EOS science proposals in the future.

Reevaluating Science Investigations

The nature and membership of EOS' interdisciplinary science teams has remained largely unchanged. In 1995 and 1996, as part of its strategy to review and possibly change the current mix of the interdisciplinary science investigations, NASA and the EOS investigators' peers in the earth sciences research community started to review the scientific merit of the current investigations. This peer review is not yet finished, but it could lead to the possible deselection of some EOS interdisciplinary science teams. NASA rejected the idea that the current investigations should be evaluated as part of a new solicitation for proposals to conduct interdisciplinary science investigations.

[7]The solicitation described five research areas, for example, one of which is the implications of continued global expansion of urbanization and high-input agriculture for the environment.

Recruiting New Investigators

The long-term growth of the EOS research community depends, in part, on NASA's ability to recruit graduate students and newly graduated earth scientists to use remotely sensed data. NASA supports prospective researchers in the earth sciences through the graduate student Global Change Fellowship program, and it supported 112 fellowships for the 1993 to 1994 academic year. As part of the September 1995 solicitation to add investigators, NASA also established a new investigator program as part of Mission to Planet Earth and solicited proposals for interdisciplinary science investigations from recent Ph.D. recipients. NASA received 65 proposals and expects to fund 10 to 15 new investigators.

RETURN ON EOS SCIENCE INVESTMENT UNCERTAIN

NASA intends to support research stemming from the September 1995 solicitation through a "funding wedge" created over a period of several years by freezing the budgets of some EOS interdisciplinary science investigators. Although NASA intends to further expand the EOS research community, its plans depend on its ability to generate future savings in the program. It remains to be seen if this will become a major constraint on the further development of EOS-related researchers.

EOS' 29 interdisciplinary science teams needs to be put in context. Over the years, NASA has stated that about 10,000 earth scientists might use EOS-related data. Given the large size of EOS' potential research community and the nonrestrictive nature of its data policy, one might think the sufficiency of EOS researchers is the least of NASA' s problems. Actually, the fact that 10,000 earth scientists may be potential users of EOS data overlooks the requirement that scientists need to be funded to conduct basic research on global climate change. We found that for this type of work, scientists analyze data when they are paid to do so. This observation is based on our review of the authorship of 172 journal articles about 2 pre-EOS-era earth sciences missions - - the Upper Atmosphere Research Satellite (UARS) and TOPEX/Poseidon. Publicly funded investigators wrote all but 10 of the articles. If NASA were to fund even a 10th of the 10,000-scientist research community, at an average of $250,000 each, it would have to budget $250 million annually. NASA requested $58.4 million for EOS interdisciplinary science in fiscal year 1996, and according to the fiscal year 1996 budget submission, funding for EOS interdisciplinary science is planned to increase to $73.2 million in fiscal year 2000.

Our observation that the size of the EOS research community is relatively small is based on a comparison of (1) the number of science teams associated with the two pre-EOS earth observation satellite missions--UARS and TOPEX/Poseidon--to their EOS-era counterparts; and (2) the ratio of the number of science teams to the raw data acquisition rate expected from the EOS core cluster of spacecraft to the number of science teams and raw data acquisition rates of UARS and TOPEX.

UARS, launched in September 1991, consists of 10 instruments that are measuring the composition and temperature of the upper atmosphere, atmospheric winds, and energy from the sun. The UARS science teams are led by 10 "principal" and 12 "theoretical" investigators. NASA broadened the UARS science community in 1994 by selecting additional teams led by 40 "guest" investigators. NASA is also funding correlative measurement teams led by 38 investigators to develop an independent database to validate and complement measurements made by UARS' instruments.[8] In the EOS era, solar energy and atmospheric chemistry measurements will be made principally by the ACRIM, SAGE, and SOLSTICE instruments and the CHEM spacecraft.[9] Currently, only 12 instrument and interdisciplinary science teams are associated with these instruments and the CHEM spacecraft. In contrast, UARS supports research conducted by 62 instrument and science teams.

TOPEX was launched in August 1992 to study the circulation of the world's oceans. The primary instrument is an altimeter that measures the height of the satellite above the ocean, wind speed, and wave height. NASA and its French partner selected science

[8]According to the Clinton administration's fiscal year 1996 budget submission, funding for UARS' operations and data analysis will cease in fiscal year 1998.

[9]ACRIM (1998) monitors the variability of total solar irradiance; SAGE (1998) provides profiles of aerosols, ozone, and trace gases in the atmosphere; SOLSTICE (2002) measures full disk solar ultraviolet irradiance; and instruments on the CHEM spacecraft (2002) measure, in part, tropospheric ozone. Dates are for the first flight of each instrument in the EOS era.

teams led by 38 principal investigators.[10] The 38 TOPEX-related science teams have about 200 members, and NASA plans to solicit additional investigators. In the EOS era, the follow-on mission to TOPEX is Radar-ALT. An instrument team has not yet been selected, but only 7 of the 29 interdisciplinary science teams currently plan to use Radar-ALT data in their investigations.

There is a striking difference between the number of (1) science teams and volume of data of pre-EOS missions and (2) the current EOS science teams and the expected volume of data from EOS. Taken together, the number, but not necessarily the size, of the UARS and TOPEX science teams is a little larger than all the EOS teams, while EOS' data rate is close to 1,000 times greater than the combined data rate of UARS and TOPEX. EOS will provide 42 million bits per second of data to 49 science and instrument teams. The corresponding ratio for UARS and TOPEX is a total of 48 thousand bits per second of data to 60 teams.[11] Although we recognize that a data rate comparison is, at best, a rough gauge of the magnitude of the data-analysis opportunities facing the earth science research community, the difference is too large to ignore.

Achieving the best science return on the large investment in EOS will require a proper balancing of EOS' three elements: space systems, information systems, and researchers.

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[10]According to the Clinton administration's fiscal year 1996 budget submission, funding for TOPEX's operations and data analysis will cease in fiscal year 1999.

[11]Includes 22 investigators for UARS and 38 for TOPEX.

It is not clear to us that NASA will achieve this balance because the science community funded to do basic research under EOS is relatively small compared to two pre-EOS era satellites. Although NASA recognizes the need to increase the number of basic researchers, we remain concerned about NASA's ability to fund more basic research through future savings that may not materialize or that may be absorbed in budget reductions.

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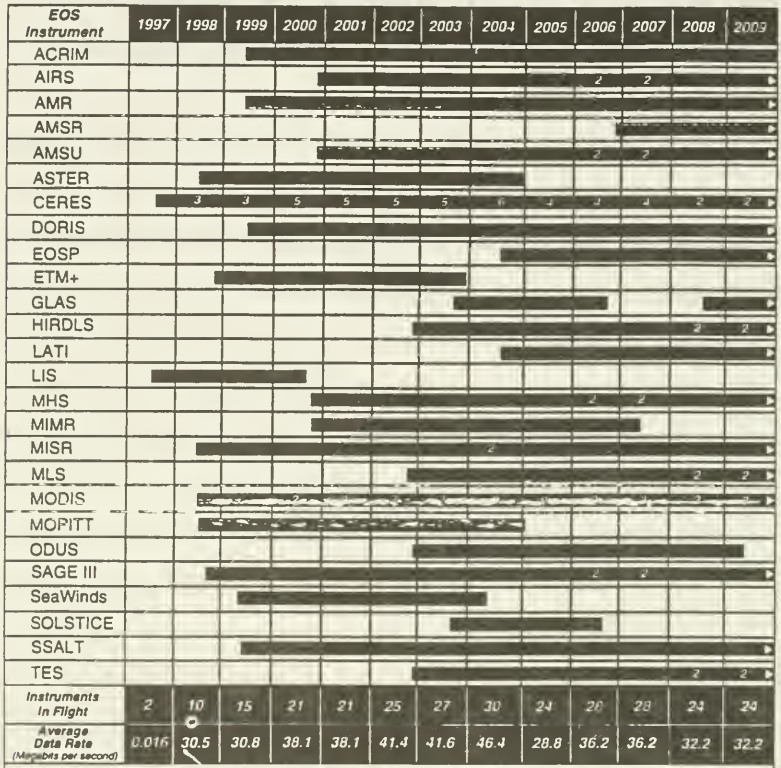
Mr. Chairman, this concludes my prepared statement. I will be pleased to answer any questions you or the members of the Committee may have.

ATTACHMENT I

EOS Instrument Flight Schedule



- Numbers in timeline bars indicate copies in orbit once the instruments have commenced routine operations.
- The "Instruments in Flight" entry is the maximum number of instruments operating at the same time during the year. For example, there will be 6 CERES instruments operating during the last half of 2004 when the following missions overlap (there is a 6-month period of overlapping operation to permit instrument intercalibration): AM-1(2 CERES), Flight of opportunity - not yet identified (1 CERES), PM-1 (2 CERES), and AM-2 (1 CERES).
- This schedule is currently under revision.

Source: NASA

Chairman WALKER. Very good, Mr. Hathaway. That's very helpful.

Dr. Kennel, we'll hear from you next.

STATEMENT OF DR. CHARLES KENNEL, ASSOCIATE ADMINISTRATOR, OFFICE OF MISSION TO PLANET EARTH, NASA, WASHINGTON, DC.

Dr. KENNEL. Thank you very much. I really do appreciate the opportunity to discuss NASA's Mission to Planet Earth. In case I don't get through all of them, I'm going to focus on three key points.

First, that Mission to Planet Earth was, is now, and will be a science-driven and peer-reviewed program.

Secondly, that we have fundamentally changed program implementation and the way we think about it. We're going to plan for scientific evolution. We're going to plan and stimulate technology infusion. And we're going to seek further international commercial and inter-agency partnerships, all with the goal of improving performance and reducing costs.

The final point which I'll only make once, Mission to Planet Earth is one of NASA's five strategic enterprises. Its development has been a priority in the last three administrations.

I'll move on to my first point.

Since 1982, there have been nine external studies, of which Professor Frieman's was the last, and of course numerous internal reviews over the last 14 years.

And from this evolving set of studies, clearly tightly link to the scientific community, there has emerged a clear set of goals and requirements for the Mission to Planet Earth program that specify our objectives and our measurement needs on the 15-year time scale, as is well known, but also to develop results on the one- and five-year time scales.

We seem to have arrived at a stable view of the degree of comprehensiveness, the science scope that is needed to address the interdisciplinary problems of Earth systems science and provide a scientific roadmap for global environmental thinking.

We have arrived at well-defined standards for coverage, calibration, continuity and timeliness of that data. And I'd just like to point out that Mission to Planet Earth's program extends far beyond the highly public issue of global warming. We will concentrate on seasonal to inter-annual climate prediction, changes in land use and land cover, atmospheric, especially tropospheric, chemistry, natural hazards.

And if we do these jobs right and add a few more measurements, we will make our contribution to improving our ability to make long-term climate predictions.

In the area of scientific and technological evolution, we've moved away from the old approach. No more will there be identical copies of the spacecraft flown to get the same measurements. We refuse to fly old technologies and address old scientific issues in the year 2017.

To accomplish this, we will institute comprehensive implementation reviews every two years to drive continuous innovation into the program, and we'll invite our scientific and our commercial and

our international partners to help us to decide what to do next in the next stage of the implementation of the program.

Already, as you have mentioned, we have studied driven technological evolution and we believe at this stage, our understanding is clear that we can accomplish our fundamental scientific goals and decrease the costs of the program beyond the year 2000 by 30 percent, perhaps more.

We understood that the budget profile extending into the next century was unsustainable.

Already, if you look at the results of what has happened thus far, we can compare specific improvements, the way the program looked between 1990 and '94, and the way we currently think it will be implemented in the years 2000 and 2004.

We've moved from very large to medium and small spacecraft. The number has increased by at least a factor of three, while achieving this 30 percent savings. The average development time is faster by a greater factor of two. The average spacecraft launched per year has increased by about a factor of five. The average spacecraft development reduced by about a factor of three.

In addition, we have scrubbed the number of EOS data products, reduced by a factor of four, and the average EOS data rate has been reduced by a factor of two.

Now, we will propose this afternoon and tomorrow to Professor Frieman's committee our response to their creative approach to the generation and the distribution of the data to a larger and more diverse community.

We understand and we've had to take some of the savings that we achieved in the front end of the program and reinvest it in order to achieve this more sustainable cost profile over the long term.

We did listen to outside advice. The Board on Sustainable Development has endorsed and has amplified and will continue to amplify this new approach.

On directed technology infusion, we have joined the New Millennium program, a cooperative NASA-private industry-university activity to develop and demonstrate next-generation technology both for spacecraft and for instruments.

In our field, the name of the game is to re-engineer and reduce the size and cost of those instruments so as to bring the cost down in the future.

We need to invest now to make the savings later.

In addition, we are going to challenge the scientific community with a new small-sat line, Earth systems science probes, low-cost small satellite program, $120 million end to end, through data reduction, comprehensive observational strategy, including ground measurements, if they need them, 24- to 36-month development time.

We cannot say to the scientific community that somebody in 1990 decided what the priorities would be in 2017. We must continue to develop our understanding.

On the commercial international and inter-agency partnerships, we do commercial data buys at the present time. We provide Landsat 4 and 5 images to our scientific community. We are awaiting the data from a purchase of the SeaWiFs.

Next year, we will launch the Lewis & Clark spacecraft and we will purchase data when our scientific requirements—when they can satisfy our requirements.

And the strategy of a comprehensive review every second year, inviting in the commercials, will encourage them to try to meet our needs and at the same time, will enable us to make timely decisions to adopt their products when they become available.

We are just about to submit for general review and circulation a new commercial strategy to promote the application of Mission to Planet Earth data, to develop partnerships in data analysis and technology development, and to make clear what our scientific interests are, so that our commercial partners can respond to those interests.

And in general, to try to create a clear and consistent Mission to Planet Earth image and role in the commercial community.

We have been working recently exceptionally closely with NOAA to try to help develop the new weather system, the converged weather system. We have incorporated NOAA interests into the New Millennium technology development program. There are at least six areas of common interests identified in NPOESS and we are working to reduce the cost and increase the capability of weather instruments, both in the polar and the geostationary orbit area.

We are working closely with MEDEA, as Professor Frieman identified.

In the international arena, 19 countries at the present time are investing $3-1/2 billion in the program of Mission to Planet Earth, and they conduct $4 billion worth of complementary missions in the same area. Much of the data, we get access to that, so that the international contribution now to this field now slightly exceeds that of Mission to Planet Earth, and we expect that to continue to grow.

Once again, we expect, with the two-year comprehensive reviews, that each time a new cooperative opportunity emerges on the international scene, we will be able to capture it and integrate it into our program planning.

So, in closing, I would just like to comment that it's certainly the case that the pace of change in the space enterprise has accelerated since the Cold War has ended. NASA has responded to those changes. Mission to Planet Earth intends to capture those changes.

We think it's time to get on with this program. We have a job to do. We shouldn't delay the start of the new comprehensive observational strategy. We fear the loss of the science and the timely applications and the information, and it is clear to us that further budget reductions, particularly in the short-term, will translate into knowledge reductions.

And, of course, as you understand, we are committed to continuously exploring opportunities to reduce the costs and to expand the scientific capability, and our posture is to do that as a matter of daily business.

In closing, the EOS program begins in 1998, and it will mark a new era in land remote sensing. With the AM-1 spacecraft, with Landsat, with Lewis & Clark, and the numerous commercial opportunities, we expect to see a major change, a flood of information

that will provide new clarity and new understanding about the processes of change that occur on the surface of the Earth.

We greatly look forward to the new era in Earth observations, and we urge you, let this revolution continue.

Thank you.

[The prepared statement and attachments of Dr. Kennel follow:]

Statement of
Dr. Charles Kennel
Associate Administrator for Mission to Planet Earth
NASA Headquarters

before the
Committee on Science
United States House of Representatives

March 6, 1996

Mr. Chairman and Members of the Committee:

I am pleased to be here today to discuss **NASA's Mission to Planet Earth**, which generates solid science results that help us better understand global changes on Earth and provide practical benefits to Americans. In doing so, it is important to focus on seven key points:

1. We must improve our understanding of the global environment.
2. Mission to Planet Earth is, first and foremost, a sound scientific endeavor.
3. NASA has dramatically changed Mission to Planet Earth while preserving a science driven approach.
4. International partnerships are an indispensable part of Mission to Planet Earth.
5. Commercial and interagency partnerships provide an all-embracing dimension to the program.
6. Technological innovation energizes the long term program.
7. We have made excellent progress - but the best is yet to come.

We Must Improve Our Understanding of the Global Environment

When the astronauts first looked back on the Earth during their trip to the Moon, they observed a planet in a constant state of change. We understand some of these changes pretty well - short term weather forecasts, hurricane tracking, and the way things grow. But we are missing a lot of other critical information, like

the kind of data we need to predict how the climate will shift a year from now, and what the effects will be on people whose livelihoods depend on that climate - farmers, water managers, fishermen.

As we have come to recognize the economic, social, and scientific need to better understand how the Earth works, the U.S. has become a leader in organizing the global effort to observe the global environment and its effects on human quality of life. NASA has developed **Mission to Planet Earth** to capture our spirit of exploration and focus it back on the Earth. Building on our observations of the Earth since the dawn of the space program, NASA is using its unique capabilities to provide a global perspective of our land, air, water, and life. Mission to Planet Earth is an essential part of the U.S. Global Change Research Program - a national program consisting of many federal agencies which is committed to studying the Earth system on a global scale.

Mission to Planet Earth has been challenged to answer the timely questions about our planet that have been raised to a high level of consciousness in recent years. Instead of being captive to whatever climate changes may occur over time, NASA and its interagency, international, and commercial partners are striving to discover patterns in climate that will allow us to predict and perhaps respond to environmental events - such as floods and severe winters - well in advance of their occurrence. Nations, regions, and individuals can then use this knowledge to prepare for these events, likely saving countless lives and resources.

We need to begin these valuable measurements now. These observations and analyses will enable long term weather prediction, greatly improving both our daily lives and longer term planning. Farmers will begin to better manage what has been the greatest risk factor in their business: the uncertainty of climate patterns. Losses of crops and livestock previously caused by shifts in seasonal weather patterns or by adverse weather conditions will be reduced by altering crop/livestock selection, exploring innovative farming techniques, or perhaps not planting certain crops during a particular season. Market forces might allow farmers in regions not under threat to increase their productive capabilities to prevent shortages. We can see the potential benefits of such improvements in knowledge just around the corner; the key is pursuing the planned measurements as soon as possible.

Our current lack of understanding affects the nations of the world in different ways. African nations are often concerned with severe droughts, while those in Southeast Asia desire to know with more precision when a monsoon may arrive. The U.S. is concerned with the likelihood of floods along the Mississippi, rainfall patterns over agricultural areas, and damaging storms along our heavily populated coastlines. Concerns about the Earth are now reaching beyond the scientific community to the business world. The trillion dollar banking and

insurance industries around the globe are beginning to see the value of Earth observation in such areas as long term climate prediction and severe storm forecasting and sea level rise. Such businesses have been predicated on a stable world climate and their well being is dependent on good intelligence about the future of the Earth's environment. Since the entire Earth is affected by climate changes, Mission to Planet Earth is an international program which will enable regional forecasts to identify potential trouble spots around the globe in the future.

Mission to Planet Earth is first and foremost, a sound scientific endeavor

While the beneficiaries of Mission to Planet Earth are many and range from farmers to the insurance industry, the program is grounded in solid peer-reviewed science. Advanced scientific endeavors are not new to NASA: we were pioneers in developing the weather, communications, and land-sensing satellites that produce data and images which are now a part of our daily lives. We learned that we must have good science before most of these practical benefits are possible.

The scientific community spelled out the critical pieces of the puzzle that we need to have in order to gain the understanding we seek. They determined the most fundamental questions which need to be answered and they described the observations needed to answer them in a timely fashion. Numerous external and internal studies over the last 14 years have helped validate and refine our science approach.

NASA's Mission to Planet Earth program is designed to address a fundamental scientific challenge: how do the Earth's land, water, air, and life all interact to produce the environment in which we live? Scientists believe that a comprehensive understanding how each of these parts of the Earth are linked to each other is the key that will help provide the "user's guide" for our planet. The potential human benefits of this understanding are broad and substantial.

To do this complex job, one must go beyond the traditional approach to studying the Earth (i.e., looking at each individual part) and establish one that is focused on the "big picture." NASA's program expands the conventional, departmentalized scientific approach to encompass the Earth as a unified system: interdisciplinary U.S. scientists from Maine to Hawaii and from the High Plains to Texas - and from more than a dozen other nations - are joined together through a unique information system to explore the complex interrelationships of Earth's land, air, water, and life. NASA will gather data which will focus on long term climate variations, changes in land cover, ozone changes, and seasonal and yearly prediction of the climate. This comprehensive approach will yield results which will enable us to address many scientific and practical questions. While many in the media have focused on global warming and ozone, the core

knowledge sought by Mission to Planet Earth and its partner programs goes far beyond these two issues - instead, it focuses on broadening our ability to understand the basic processes and interactions which govern the global environment. Only from such a basis of broad understanding will we be best able to address the many scientific and practical questions currently facing us.

The primary means for making these important measurements are space-borne satellites; that is NASA's most important contribution to the overall research effort. The perspective from space is critical to provide the global coverage and precision we must have to discern the intricate interactions of our land, air, water, and life. Only from above can we observe places where it is impossible (or very difficult) to make ground observations - like distant parts of the world's oceans, deserts, and polar regions. Space observations enable us to measure the globe on a regular basis and to do so far more cost effectively than would be possible from the ground. Using this "big picture," scientists can then build computer models that simulate how the Earth behaves. More importantly, they can use this global understanding to focus on what people really care about: what is happening in their state or region. In essence, the global nature of the science in Mission to Planet Earth is actually what will enable most of the practical benefits closer to home. Though ground and aircraft measurements certainly play an important role for these pioneering scientists, only space can provide the economical means for providing these observations on a global scale.

Over the course of the last three Administrations, NASA and its partners in the U.S. Government and around the world responded to this challenge by developing complementary and interconnected observation, data, and research systems designed to provide the most cost-effective means of acquiring and analyzing the highest-priority measurements. They sought to carefully define the scientific and calibration standards for the data, both to ensure uniform quality of information and to help simplify its later analysis and use.. The resulting science will provide US leadership in the development of an international consensus on the state of the Earth today and in the future. We are confident that we have developed a balanced approach that focuses on a logical and comprehensive sequence of short term studies and analyses that will produce both near term benefits and future results, such as long term predictions of climate change.

NASA has dramatically changed Mission to Planet Earth while preserving a science driven approach

The pace of change in the space enterprise has accelerated dramatically since the end of the Cold War. Unique partnership opportunities and unforeseen technological breakthroughs are emerging at a rate previously thought impossible. NASA has recognized that a program with the long term horizon of

Mission to Planet Earth needs to be ready to take advantage of such changes. Thus, in the last year, we have radically changed our management philosophy and approach. We are ready to capture the change and use it to the benefit of the program, and thus, the American people.

Though the current changes are still evolving, we have already made extensive modifications to the Mission to Planet Earth program since its inception. Near term Earth Observing System (EOS) costs (through 2000) have already been reduced from $17 billion to $7.25 billion since 1990. We are vigorously pursuing technological changes to **decrease out year costs by 30% -- saving billions** of taxpayer dollars. We plan to incorporate a comprehensive review of the program every 2 years for future infusion of technology and other improvements to enhance measurements and capability while reducing costs still further. Between 1990 and 2004 we will truly become a better, faster, cheaper program by realizing the following goals:

- Total number of spacecraft planned for EOS will increase by a factor of at least 3, having evolved from very large spacecraft to medium and small spacecraft, all while assuming the budget reductions noted above
- Average development time for a spacecraft will have gotten faster by greater than a factor of 2
- Average number of spacecraft launched per year will have increased by almost a factor of 5
- Average cost for developing a spacecraft will have gotten cheaper by a factor of 3
- Total number of EOS products reduced by a factor of 4 (accomplished)
- Average EOS data rate reduced by greater than a factor of 2 (accomplished)

We have also released the draft Mission to Planet Earth Science Plan, outlining the science focus areas of the program, which will provide a roadmap for obtaining the science we need to answer critical questions about the environment. It is essential to keep all the changes we make in perspective – science must always remain the top priority of our program and vehicles like the Science Plan help keep us on track.

NASA is also committed to finding innovative ways of getting the information we collect out to all potential users. Our data and information network currently allows approximately 12,000 people to access our information each month, an effort made easier with the recent addition of new Internet tools. In the years ahead, this number will grow astronomically, but we are confident that our ability to meet this demand will grow correspondingly. Pursuant to recommendations from external review groups, we are working on innovative ways to generate and distribute the data which will enhance the overall flow of information to better serve not only the scientific community, but also the business community and the general public.

But NASA's outreach to non-science oriented groups goes beyond our data system. We are developing partnerships on three fronts: the international community, the commercial sector, and other federal agencies. This new way of doing business will be mutually beneficial to all the partners, allowing each to contribute their unique expertise in return for their particular needs. We expect these partnerships to grow substantially in the years ahead, allowing the cost of data to decrease while the applicability and usefulness of the information to the general public will grow.

We are also pursuing innovation, in the form of new technology, new science capabilities, and new ways of doing business. To achieve the reductions we have forecast for the future of the program -- and to enable ever greater reductions over time -- we will move forward along this dual track. The next several sections highlight some of our efforts in each area.

International partnerships are an indispensable part of MTPE

Global questions require the cooperation of all concerned nations of the world. The U.S. cannot accomplish this type of comprehensive research task alone -- international collaboration is vital to the success of our efforts. However, U.S. leadership in this cooperation is both appropriate and essential to guiding the effort toward practical answers and in a direction that preserves the health of our people and our industries. In addition, extensive international cooperation is essential to build confidence in the data collected and allow broad consensus in reaching scientific conclusions about the nature of the global environment.

Mission to Planet Earth was conceived as a fundamentally international program and has benefited from extensive international consultation and involvement since its inception. Since the 1980's, we have been working very closely with our partners in Japan, Europe, and Canada to coordinate observational requirements, data standards and exchange, and research planning to avoid unnecessary duplication of effort. This involves flight of international instruments on U.S. spacecraft, flight of U.S. instruments on partner spacecraft, agreements to exchange data acquired through these observations, coordination and conduct of joint scientific research campaigns (both using satellites, aircraft, and ground resources), and constant scientific evaluation of research findings and direction.

Through the first phase of the program, ***there are 19 countries involved who have already directly invested $3.5 billion in Mission to Planet Earth.*** At the same time, those nations have also invested nearly $4 billion in complementary international Earth observation missions for which the U.S. provides no financial support but does receive the data, and coordinates activities to avoid unnecessary overlaps in measurements. The U.S. will have access to the

results of these missions through of extensive data exchange agreements which are already in place or being negotiated. This total $7.5 billion ***international investment is roughly equal to the U.S. investment*** in Mission to Planet Earth during the first phase of the program.

A perfect example of this cooperation will come in August of this year, with the first international mission in the coordinated International Earth Observing System constellation, the Japanese Advance Earth Observation Satellite (ADEOS). It carries two American instruments: the NASA scatterometer instrument and an American ozone instrument. It also carries a French sensor to enable better atmospheric corrections in Earth observing data, along with several Japanese instruments. NASA and Japan will share in the data acquisition and processing responsibilities. Our agreement with our Japanese partner commits them to provide access for us to all their data and products, and for us to provide access to NASA's Earth Observing System data in return. The negotiations for the follow-on mission, ADEOS-2, which will provide continuity for the scatterometer data, are underway right now.

In addition to such existing cooperative arrangements, NASA is at the forefront in the development of an integrated international strategy to coordinate data collection worldwide and to commit nations to collect and share environmental information. We are working to seek additional contributions from many other nations of the world, most likely through non-space measurements (such as ground and aircraft observations) and research.

Commercial and interagency partnerships provide an all-embracing dimension to the program

NASA plans to actively work with new partners in the commercial, university, and interagency communities. The type of studies being pursued by Mission to Planet Earth require us to take a close look at how to more actively involve external partners in all aspects of planning and implementation of the program. NASA has received a great deal of excellent advice and input over the last two years on these innovative ways to do business and has taken steps to even further expand the role of such partnerships in the years ahead.

NASA's Mission to Planet Earth has recently developed a **commercial strategy** which is designed to drive down the cost of science data by exploiting cutting-edge industry technologies and information systems and by working with the commercial sector to develop new technologies which are mutually beneficial to government and business. As capabilities emerge in the commercial sector to provide data that meets our science requirements, we will take advantage of them. As noted earlier, by reviewing program implementation every two years, we will ensure that we are constantly pursuing the most cost-effective approach to acquiring needed observations. NASA will also engage in partnerships with

the private sector to encourage a thriving new industry which transforms data into practical applications which can be useful in the lives of everyday Americans and their businesses in areas such as agriculture, forestry, fishing, and mineral extraction. NASA will continuously inform and consult with industry to ensure that our planning for Mission to Planet Earth takes a coordinated government-industry approach which provides the best science and the newest technology at the lowest cost. While we will actively encourage commercial involvement in Mission to Planet Earth, NASA will in no way duplicate activities that are and can be developed by the private sector on their own.

NASA continues its long partnership with **the National Oceanic and Atmospheric Administration** (NOAA) to enhance operational weather capabilities and with both NOAA and USGS on critical land observations. NASA's technology has contributed directly to improved weather forecasting that has occurred since the sixties. In the last year, NASA and NOAA have taken a number of steps to much more closely coordinate their activities in the area of Earth observations, with a focus on providing enhanced services for a lower overall cost. In looking at observational requirements, data dissemination, and physical location, the two agencies are confident that they will meet their objectives.

Specifically, the NOAA/DOD/NASA converged weather system is an excellent example of this enhanced cooperation. NASA's critical role in this effort is as developer of advanced technology instruments and other contributions for the converged system. NASA is developing a closer alignment with NOAA and DOD in which the instruments developed by this tri-agency effort would meet both operational and research requirements potentially resulting in very significant cost savings. Six areas of common interest have been identified, and one in particular would merge the functions of four instruments into one, which would reduce the mass of the instrument by a factor of three and the power needed by a factor of four.

Another interagency relationship which has been important to MTPE involves the **national security agencies** of the U.S. and Russia. The Administration has directed an effort within the U.S. intelligence community to determine the potential applications of years of national security data to environmental issues. NASA, through MTPE, has been actively pursuing the possible uses of this data for the past few years, and we have incorporated elements of this activity into our present program. We are also actively working with Russia to determine the applicability of former classified data to the environmental research community. While these efforts make MTPE a stronger program, they cannot substitute for a major civil research effort to understand global change. National security data lacks some of the key scientific precision needed for understanding global climate change, and does not often have continuous observations over a 10-15 year cycle as required by the scientific community. Given the nature of the

intelligence business, there are also limits to the sharing of this data to the world research community. Where opportunities exist for utilization of this data, the Administration is taking every effort to do so.

Technological innovation energizes the long term program

NASA has always been at the forefront of new technology and approaches, and the Mission to Planet Earth program is no exception. While science is the foundation of the program - and the fundamental questions it is designed to answer - we are constantly examining ways we could improve program implementation. As noted above, we are moving forward on several initiatives designed to help the program evolve effectively into the future.

One strategy for capitalizing on new scientific understanding and emergent technologies is the design of a series of small, rapid-development science missions. These low cost small satellite series will incorporate today's cutting-edge technologies and provide MTPE with important global change data. Called Earth System Science Pathfinder (ESSP) missions, the satellites would each be limited to a life-cycle cost of $120 million or less including the launch vehicle and two years of operations and data analysis, with development times of 24 to 36 months. Following the lead of the Lewis and Clark missions, these would involve new commercial partnerships and contracting approaches with minimum Government oversight. Missions would be competitively selected through peer-reviewed Announcements of Opportunity, with science objectives and cost as the primary selection criteria. This program will provide science complementary to the present suite of instruments and encourage foreign participation.

Another innovative NASA program, **the New Millennium Program (NMP), will be a coordinated NASA/private industry activity incorporating next generation technologies such as lightweight, low cost instruments.** New Millennium program focuses on the demonstration of technologies and techniques which can enable science missions of the future. This innovative program will develop new technologies to improve the performance and decrease the cost of currently scheduled NASA missions. These innovations are critical to realizing the life-cycle costs projected by Mission to Planet Earth's recent reshaping exercise. Demonstration of technology is the prime objective of New Millennium, while science investigations are of secondary importance. Key technologies and demonstration missions have been identified and flight opportunities should begin in late 1997 with the first science mission slated for 1998. In both ESSP and NMP, we are confident that by investing in innovation today, we can substantially reduce costs in the future. We are committed to continually evolving Mission to Planet Earth into a premier 21st century scientific enterprise.

Finally, with regard to innovation, neither NASA nor the business community can predict all of the ultimate uses of this data with any certainty. But given the types of measurements planned and the increasing sophistication of the user community, it takes little imagination to think that the science data and understanding we produce today and tomorrow will enable the private sector to develop myriad marketable data products (some of which we can't even project today). Mission to Planet Earth is part of a greater research and development investment in the future which is needed by the US to remain competitive in world markets.

We Have Made Excellent Progress, But the Best Is Yet to Come

Results from Mission to Planet Earth are already changing the way we think about our global environment.

Recent Results. The joint U.S./French oceanographic satellite has demonstrated a technique for precisely measuring changes in sea level, and has measured a rise in that level over the last three years. Though not sufficient to determine a trend, the findings are important in understanding how the oceans behave. Observations by that satellite and other research has led to ground-breaking findings on the behavior of the El Niño phenomenon, which causes massive fluctuations in U.S. weather every couple of years. These findings have enabled scientists to predict the El Niño more than a year in advance, enabling those potentially affected to alter crop and other planning. Aircraft missions and upper atmosphere satellite observations have conclusively proved that annual Antarctic ozone loss is due to the presence of human-produced chemicals that have migrated to the upper atmosphere. NASA-developed weather satellites are providing state-of -the-art observational/predictive capability which allows us to plan for upcoming weather events and prevent loss of life from hurricanes and other destructive phenomena.

Last year we launched a lightning detecting mission which will help us better understand how serious storms form and evolve, yielding practical weather forecasting benefits. Three shuttle missions have examined the effect of the sun's radiation on the Earth, while two others demonstrated an exciting new radar technique for examining the vegetation and land features of the Earth's surface. That same radar technology has also been used to identify previously hidden archeological ruins and discoveries in the Middle East and Southeast Asia. A recent aircraft campaign provided surprising data on the boreal forests on the Northern Hemisphere, suggesting that scientific understanding of the amount of moisture produced by such forests would have to be modified.

The Near Future. This year, NASA will launch Lewis & Clark, two collaborative missions with private industry which will provide scientists, businesses, and governments with extremely detailed images of the land. The Lewis mission is

an example of a process in which NASA validates the technology enabling the private sector to create new markets: it will use 384 color bands (compared to 7 on Landsat) for close-up land images. Next year, a private company will launch SeaStar, a spacecraft designed to provide NASA will scientific data on life in the oceans--data which may also be marketable to the fishing, oil, and shipping industries. We will also join with the Japanese on a joint mission to study tropical rainfall, which is very poorly understood today and which is an essential element in the global climate change equation.

In 1998, the Earth Observing System (EOS) will begin the first integrated measurement of changes in global climate as well as providing practical information for business, farming, forestry, and fishing. Using a series of different satellites, EOS will look at the Earth in a totally new way: rather than focusing on just one aspect (land or ocean or air), EOS satellites will carry instruments designed to observe multiple aspects of the planet. By getting this kind of information, scientists will be able to see the interactions and enable to move beyond a description of "what" is happening to an understanding of "why."

EOS is the first comprehensive system designed specifically to study the Earth as a complex series of interactions between life, air, water, and land. EOS is composed of 24 essential measurement areas which a consensus of scientists believe will answer the complex questions of climate change. Over a 15-18 year period, EOS satellites will fly in over most of the Earth's surface, gathering data such as global changes in the atmosphere, land surface, pollution, and water resources. What were once studied as isolated events will be examined as interconnected and interactive forces which form a comprehensive snapshot of the Earth as a whole.

During 1995, NASA "reshaped" the EOS program to enable it to incorporate both new technological capabilities and science needs in the future. The reshape effort focused on the 2nd and 3rd series of EOS measurements, examining ways that the program could maintain scientific continuity with the measurements in the first series of flights while employing new technology instruments to reduce the program's costs and increase its flexibility.

In fall 1995, the National Academy of Sciences presented a set of recommendations through its Board on Sustainable Development (BSD) regarding NASA's planning for EOS. The Academy affirmed NASA's approach to implementing the first series flights of EOS "without delay" and endorsed the results of the reshape exercise for the 2nd and 3rd series of EOS, particularly as they related to the incorporation of new technology and approaches in making measurements. The Academy also recommended that NASA maintain a science-driven approach, which we believe is satisfied by the release of our Science Research Plan for the next four years, which outlines Mission to Planet

Earth science priorities. NASA is presenting its responses to all the Academy's recommendations at a meeting of the BSD this week.

EOS Data and Information System. In this age of information, a state-of-the-art, evolving system to provide data is essential. Mission to Planet Earth has designed the Earth Observing System Data and Information System (known as "EOSDIS") to relay large amounts of information to scientists, educators, governments, businesses, and the general public. Through EOSDIS, any data set can be accessed (via the Internet and other means) by thousands of users at the same time throughout the world. As the amount of data and the number of people using the system increases, the system is designed to take advantage of advances in technology to provide timely and comprehensive information.

To derive optimal benefit from climate change research, EOSDIS is designed to provide information at the lowest possible cost (the marginal cost of reproduction) to anyone, anywhere on Earth. The more diverse the group of people working on a project, the greater the opportunity for discovery. And the data system may also influence behavior around the world. For example, a Swedish scientist writing a paper on deforestation in Germany may influence a Chinese forestry official to take steps to prevent repeating a harmful situation in his own country.

In their report, the Academy recommended that Mission to Planet Earth reconsider the means by which it planned to generate and distribute data products. As noted above, NASA is actively considering innovative approaches to accomplish this and we will consult with the Congress before any final decisions are made.

Mission to Planet Earth Is Moving Forward

From a scientific and practical basis, we urgently need to better understand how our global environment works. We have, in concert with our numerous domestic and international partners, designed a system of observation and analysis to meet this challenge. We know that, because it is rooted in solid science, this system will provide us with both a wealth of near-term benefits and answers to fundamental, long-term questions. But, to preserve this continuity in science, we have radically altered our philosophy of the program, opening ourselves to new opportunities and approaches. Mission to Planet Earth will always be an evolving cutting-edge science program: we are committed to proactive measures to continually infuse new technologies as they emerge and create an environment for enhanced commercial opportunities.

Once before, NASA missions and people helped change the way we think about the Earth. Over time, we are confident that the data and information from

Mission to Planet Earth will help us and our children think clearly about the world we all live on.

Thank you.

CHARLES F. KENNEL

Associate Administrator for
Mission to Planet Earth

NASA Headquarters
Washington, DC

Effective January 6, 1994, Charles F. Kennel, a professor in the UCLA Department of Physics, has been appointed to a two-year post to direct NASA's Mission to Planet Earth--the space agency's long-range research program to study the Earth's environment.

As Associate Administrator for Mission to Planet Earth, Dr. Kennel will manage NASA's program that studies the interaction of the various elements -- air, water, land, and life -- that make up the Earth system. Mission to Planet Earth strives to improve understanding of the Earth and how it is changing, with research on some of the most critical topics facing us today: global warming, ozone depletion, and deforestation. In close cooperation with other Federal agencies and international partners, Mission to Planet Earth conducts a comprehensive program of observations (from satellites, aircraft, the Space Shuttle, and the ground), data analysis, basic research, and modeling exploring a broad range of global change issues. The program is designed to provide policymakers with the information needed to make long-term decisions on the future of the Earth's environment.

Dr. Kennel has a long and distinguished career in space science. He received an A.B. from Harvard College in 1959 and a Ph.D. in Astrophysical Sciences from Princeton University in 1964. He has been a tenured member of the UCLA Department of Physics since 1967, and was its chairman from 1983 to 1986. He became a member of UCLA's Institute of Geophysics and Planetary Physics in 1971, and is an Associate Director of UCLA's Institute for Plasma Physics and Fusion Research. He is author or co-author of over 225 experimental and theoretical publications in plasma physics, space plasma physics, planetary science, astrophysics, and nonlinear science.

Dr. Kennel has been a Fulbright scholar, a Guggenheim scholar, and a Fairchild Professor at the California Institute of Technology. He is a fellow of the American Geophysical Union, the American Physical Society, the American Association for the Advancement of Science, and a member of the International Academy of Astronautics and the U.S. National Academy of Sciences.

UNDERSTANDING OUR CHANGING PLANET:

NASA's Mission to Planet Earth

Fact Book

May 1995

UNDERSTANDING OUR CHANGING PLANET:

NASA's Mission to Planet Earth

In the last three decades, we have changed the way we think about our planet. Apollo astronauts observed the Earth as a blue marble against a vast background of darkness -beautiful, but finite and ever changing. Our missions to other planets have revealed them to be fascinating and diverse, but also sterile. We know of no place like Earth.

NASA has developed a program, called **Mission to Planet Earth**, that captures our spirit of space exploration and focuses it back on our own planet. Only from space can we obtain the global perspective needed to better understand how all of the parts of the Earth's environment - air, water, land and life - interact and make life possible. Data and analyses from Mission to Planet Earth, which includes extensive cooperation and contributions from other Federal agencies and other nations, are revealing some of the Earth's secrets. But the most revealing - and useful -- discoveries are yet to come.

By using satellites and other tools to study the Earth, we hope to expand our understanding of how natural processes affect us, and how we might be affecting them. Such studies will yield improved weather forecasts, tools for managing agriculture and forests, information for fishermen and coastal planners, and, eventually, an ability to predict how the climate will change in the future.

Just as the first weather and communications satellites fundamentally changed our way of thinking about those fields, so the elements of Mission to Planet Earth will expand our perspective of the global environment and climate. Working together with the nations of the world, we are well on our way to improving our knowledge of the Earth and using that knowledge to the benefit of all humanity.

NASA's Mission to Planet Earth

Why do we need to study the Earth from space?

HUMAN SOCIETY IS VULNERABLE TO ENVIRONMENTAL CHANGE

WE ARE ALTERING THE EARTH ON A GLOBAL SCALE

WE ARE UNCERTAIN HOW THESE CHANGES
WILL AFFECT THE EARTH

NASA'S UNIQUE CONTRIBUTION
IS THE GLOBAL VIEW FROM SPACE

LEADING THIS GLOBAL EFFORT
IMPROVES AMERICA'S STRATEGIC POSITION

WE HAVE MADE EXCELLENT PROGRESS -
WITH MUCH MORE TO COME

HUMAN SOCIETY IS VULNERABLE TO ENVIRONMENTAL CHANGE

Why is global environmental change important to society?

- **Earth's environment is in constant change.** Some of these changes, like tornados and hurricanes, are rapid and violent. Other events, like earthquakes and volcanoes, occur suddenly but are the result of pressures in the Earth's crust which have been building for millions of years. Our climate can change over decades, centuries, and even millennia (the last ice age was one such change). More immediate effects of a changing climate can be seen in altered weather patterns.

- **Single climate change events can cause global effects.** The eruption of Mt. Pinatubo in the Philippines in 1991 was one of the largest ever recorded. It spewed so much material into the atmosphere that it lowered the average temperature of the planet by almost one degree for several years. Another major climate event is the El Niño in the Pacific Ocean. While we are not sure why the El Niño occurs, records show that it has been happening for hundreds of years, on a fairly regular basis. When it does, it profoundly affects weather patterns, causing floods and droughts in different parts of the world. Many researchers believe the 1993 Mississippi and 1995 California floods were caused by the El Niño. In the last decade, the pattern of El Niño occurrences has increased dramatically, though we're not sure why.

- **Environmental change can be costly to society.** The U.S. Government estimates that natural disasters cost the U.S. an average of about $1 billion each week. Improving our ability to understand, predict, and respond to these events could give us the tools to help reduce these staggering losses. Economic consequences of changing weather patterns and land use practices are harder to define than those for disasters, but such effects can be significant and could, potentially, be mitigated.

- **Changes occur on different timescales.** Over decades and centuries, climate changes may affect migration of species, rainfall patterns, expansion of deserts, and how people live. While some changes take thousands of years, others can occur within a single generation. Human activities may be altering the pattern and timing of climate change, but much more study is needed.

- **The Earth is an incredibly complex planet.** Many interactions between the Earth's systems of air, water, land, and life remain clouded in uncertainty and mystery, and hard data on some of Earth's processes are sparse . Lacking this knowledge means we are unable to explain why major climate events occur, where they will strike, or how often they might happen. Understanding these environmental changes may help us predict how they will affect us and perhaps enable us to adapt.

WE ARE ALTERING THE EARTH ON A GLOBAL SCALE

How are humans affecting the global environment?

- **Humanity is capable of affecting the planet.** As Earth's population grows and economic activity expands, our ability to cause global scale changes in the environment increases. Some basic facts illustrate this impact:
  - There are more than five billion people now on the planet; population is expected to increase by more than half in the next 30 years.
  - Global economic activity is expected to more than double during that same period.
  - About one third of the Earth's surface is already under agricultural cultivation.
  - Africa will have to support four times its present population in just the next 60 years, according to current projections. Land degradation, soil erosion, and climate variations threaten much-needed increases in food production.
  - Astronauts in space are often able to see changes on the Earth's surface from mission to mission. It is also possible to see national boundaries from space, simply by observing different land use patterns.
- **A threat to the ozone layer.** Use of human-produced chemicals (notably chlorofluorocarbons, or CFCs) have depleted portions of the protective ozone layer in the atmosphere. This thin layer of ozone molecules stops most of the harmful ultraviolet radiation from the Sun. NASA research helped identify, and later prove, the link between the chemicals (used in air conditioning, refrigerators, and industrial processes) and global ozone depletion.
- **Increased emissions spark debate over potential global warming.** Over the next human generation, projected rates of industrialization and deforestation will cause carbon dioxide and other greenhouse gases to reach unprecedented levels in the atmosphere, continuing their increase of the last 150 years. Scientists agree that such a buildup should tend to make the planet warmer, but they don't know how the Earth will actually respond. Though some suggest that "global warming" will result and cause rising sea levels and fiercer storms, no one knows for sure. It is very important that we understand how the Earth will react.
- **We're not sure what will happen.** While we do not know precisely how population and economic growth will affect the global environment, it could increase the effects of the changes cited above and may also lead to other environmental changes of a global or regional nature. NASA's Mission to Planet Earth will observe and analyze the cumulative consequences of potential global climate changes.

May 3, 1995

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WE ARE UNCERTAIN HOW THESE CHANGES WILL AFFECT THE EARTH

What do we need to understand?

- **Laying the groundwork for further study.** Scientists studying the Earth's environment began working together more than ten years ago to better understand and predict climate change and its consequences. They have collected data, made surprising discoveries, and begun to unravel mysteries of the global environment. But this is just the beginning. We need to collect sufficiently accurate data about the climate system as a whole, so that we can develop reliable projections to tell us how particular regions might be affected.

- **We must figure out how everything is linked together.** The key to gaining a better understanding of the global environment is exploring how the Earth's systems of air, land, water, and life interact with each other. This approach - called *Earth system science* - blends together fields like meteorology, oceanography, biology, and atmospheric science. It is in interactions among the Earth's systems that our base of knowledge is most limited. Having this information will enable an informed and objective discussion about the future of the planet.

- **The U.S. has a coordinated research program.** Recognizing the need for timely, accurate information, the U.S. is carrying out a comprehensive initiative to better understand Earth. This program - called the *U.S. Global Change Research Program* - involves a closely coordinated effort among more than a dozen Federal agencies that have expertise in studying the Earth. NASA has been, and continues to be, a leader in these research efforts.

- **Studying the climate yields more than just good science.** Despite its research importance, this effort is not simply a scientific exercise. While the first weather satellites were designed by NASA to help scientists better understand weather patterns, they quickly became the means by which forecasters warn people of approaching storms, including blizzards, hurricanes, and tornados, likely saving tens of thousands of lives. In the short term, we should be able to use the information we acquire to predict climate a year in advance, giving forecasters a more sophisticated tool in predicting the weather.

- **This long-term research has many practical, near-term benefits.** Farmers, foresters, fishermen, businesspeople, and educators will be able to use the information from this initiative to improve their productivity and competitiveness.

- **We will learn as we go.** It is likely that there are factors involved in climate change and its effects on the environment and human health and activities that we will only discover as our understanding evolves.

NASA'S UNIQUE CONTRIBUTION IS THE GLOBAL VIEW FROM SPACE

Why is NASA involved in studying the Earth?

- **The best way to study the Earth as a whole is from space.** Satellites and aircraft look at all parts of the Earth - land, oceans, air, and life - and how they affect one another. They give us a reliable way to compare different regional and local environmental changes with the global "big picture." Using this perspective, NASA's space research promotes international confidence in our understanding of the global environment.

- **Space offers an objective view of the entire planet.** NASA data are already being used to verify compliance with, and progress on, international environmental treaties, and NASA scientists play a major role in organizing and leading international scientific assessments of major climate issues. Space observations offer a unique means of understanding the Earth without regard for national boundaries or political pressure. These observations and analyses will provide an objective, scientific basis for the nations of the world to work together to address truly global issues.

- **NASA has the experience to do the job.** Going back to the 1960's, NASA has developed the expertise in space research and development needed to make the precise measurements required by Mission to Planet Earth to enable scientists to generate sound discoveries about the environment.

- **NASA has a heritage of innovation.** The Mission to Planet Earth program reaches beyond such traditional scientific disciplines of oceanography, atmospheric chemistry, and geology toward an interdisciplinary approach that is necessary to make accurate assessments about our complex Earth.

- **NASA helps America lead.** The nations of the world look to the United States for leadership in the development of precise measurements that will lead to advanced scientific knowledge and sound policy decisions for the next century. NASA-supported scientists and engineers have been at the forefront of many of the major environmental discoveries over the last 30 years.

- **We are addressing the most important issues.** We are developing truly comprehensive, global measurements of the Earth as a whole to provide numerous practical benefits and to address uncertainty surrounding the likelihood of problems such as global warming, ozone loss and rising sea levels. NASA's measurements are designed to help answer the most important research questions regarding the workings of the global climate.

LEADING THIS GLOBAL EFFORT IMPROVES AMERICA'S STRATEGIC POSITION

Why is this effort important to our international standing?

- **Environmental issues cross national borders.** America cannot avoid global environmental issues nor can we resolve such issues in isolation. Environmental problems of other countries or regions - and their means of addressing them - can affect U.S. interests. Our leadership in this research effort provides a starting point for international cooperation in addressing these issues, which will help ensure a "level playing field" for American commerce on environmental matters.

- **We must work toward a scientific consensus.** Trustworthy information and shared scientific understanding provide an objective basis for making decisions about the environment. NASA's Mission to Planet Earth strives to help enable an international scientific consensus, based on valid science and objective observations, which can form the basis for collective and individual responses.

- **A global effort helps build scientific trust.** Other countries will be more willing to take appropriate steps to address environmental problems because their own scientific communities have taken part in developing the research - and resulting understanding - and because they have full access to the basic data and analyses.

- **International cooperation is vital.** The vast majority of Mission to Planet Earth efforts - including most of the missions in the Earth Observing System (EOS) program - involve some type of international cooperation. U.S. leadership has also stimulated other governments to provide their own complementary satellites and sensors, to interconnect their data systems and share data, and to support scientific research that contributes to understanding the global environment.

- **Environmental understanding helps us use resources wisely.** Better stewardship of the global environment may help alleviate current or anticipated natural resource shortages (e.g., water, food) in certain parts of the world. This stewardship requires improved understanding of Earth system processes so that resources can be managed more efficiently.

- **U.S. research leadership makes economic sense.** U.S. leadership in setting the scientific agenda in global change research allows us to position our industry and our research enterprise at the forefront of developing environmental products and services to meet growing global needs.

WE HAVE MADE EXCELLENT PROGRESS - WITH MUCH MORE TO COME

What have we learned? What else will we learn?

- **Some good news on ozone.** Working closely with other agencies and industry, NASA was a leader in providing observations and analyses on ozone depletion that prompted the U.S. and other nations to sign treaties phasing out production and use of CFCs. Recent NASA and NOAA measurements indicate these agreements are beginning to work (by reducing pollutant levels).

- **Ocean research at the cutting edge.** A NASA/French satellite is making the most precise measurements ever of whether global sea levels are rising and how the El Niño phenomena affects our weather. NASA will buy data from a commercial satellite (to be launched this year) to aid in studies of global ocean plant life.

- **Breakthrough in understanding deforestation.** NASA analyses of satellite and ground data revealed the rate of deforestation in the Amazon was not as rapid as originally thought, though effects on biodiversity were greater than expected. These analyses demonstrated the usefulness of satellite data in making accurate estimates of deforestation.

- **Capability and discoveries will increase yearly.** Planned activities include:

  - In 1997, a NASA/Japanese satellite will make the first measurements of tropical rainfall, which drives global atmosphere and ocean circulation patterns and significantly affects global climate.

  - In 1998, NASA's *Earth Observing System* (EOS) will begin providing the first integrated measurements of changes in the global climate and also yielding an unprecedented wealth of information for use by businesspeople, farmers, foresters, fishermen, land use and coastal planners, educators, and the public.

  - By 2000, NASA instruments will have precise measurements of sea levels, El Niño events, and deforestation rates in South America and Southeast Asia, all of which will serve as benchmarks against which to measure and analyze changes.

  - In the next ten years, NASA measurements will enable scientists to construct more accurate global change models which will begin to explain how the interconnected elements of the environment work together to affect life on Earth.

  - During the early 21st century, scientists should be able to determine whether the Earth is warming or sea levels are rising, and, if so, what effects are likely to result.

  - Using measurements taken by NASA and others, the private sector applications industry in remote sensing should expand to meet the potential demand of businesses and all levels of government--these data will have applications that are only limited by the imagination and resources required to add value to the data.

Mission to Planet Earth

Selected Science Issues

HOW DOES "EL NIÑO"
AFFECT OUR WEATHER?

WILL THE EARTH GET WARMER?

WILL SEA LEVELS RISE?

IS THE OZONE LAYER
STILL IN TROUBLE?

NASA Facts

National Aeronautics and
Space Administration
Office of Mission to Planet Earth
Washington, DC 20546
AC 202 358-1547

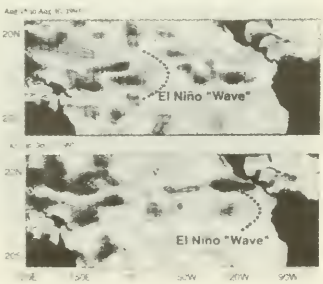
April 1995

How Does El Niño Affect Our Weather?

In many ways. El Niño is a climate disturbance that occurs every two to five years in the Pacific Ocean. A region of warm water forms in the western Pacific and moves toward South America. In doing so, it alters weather and rainfall patterns, wind directions and even the jet stream, in both the tropics and the northern latitudes of our hemisphere.

Though scientists still do not fully understand how it forms, they do believe that El Niño conditions may have contributed to the 1993 Mississippi and 1995 California floods, as well as to drought conditions in South America, Africa, and Australia.

NASA's role: A joint U.S./French satellite is providing the most precise measurements ever of El Niño's effect on the ocean surface and its progress as a "wave" across the Pacific. Additional study by NASA scientists and other researchers will enable us to understand the interactions between the ocean and the atmosphere during an El Niño, to more accurately predict how it will affect the weather, and perhaps to prepare for its occurances.



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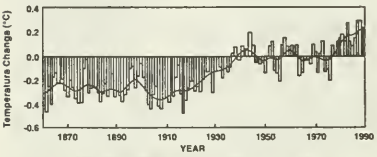
Will the Earth Get Warmer?

We're not sure. We do know that humans—as a result of growing population and industrialization— are putting an increasing amount of carbon dioxide and other gases into the atmosphere. These gases are building up and should trap energy from the Sun like a greenhouse.

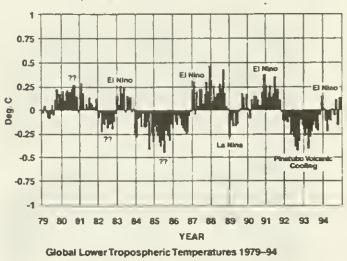
However, no one knows for sure how this buildup will affect our climate. One hundred twenty years of ground temperature records seem to show some warming, but 15 years of satellite data on the middle atmosphere show no long term trend. In neither case do we know what is causing temperature changes or whether they are part of a natural cycle. Scientists cannot yet predict accurately how the Earth's complex systems will respond to the increasing emissions.

Ground Temperature Record



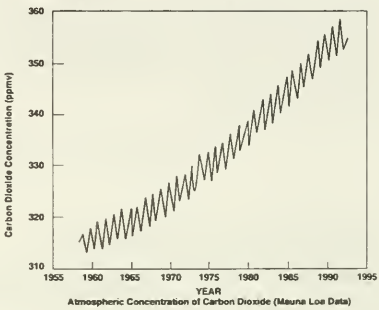
Global-mean combined land-air and sea-surface temperatures, 1861-1989, relative to the average for 1951–80.

Satellite Temperature Record



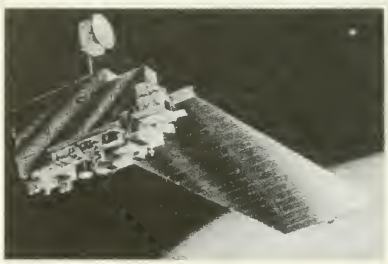
Global Lower Tropospheric Temperatures 1979–94

Atmospheric Carbon Dioxide Levels Are Rising



Atmospheric Concentration of Carbon Dioxide (Mauna Loa Data)

NASA's role: We are working with other agencies and nations to gather the scientific evidence to solve this mystery. Later this decade, NASA will fly a series of satellites—the Earth Observing System—designed to study how the different parts of the Earth's environment (air, water, land, and life) all interact. This data will help us to better understand how Earth's climate may be changing and what the effects will be.



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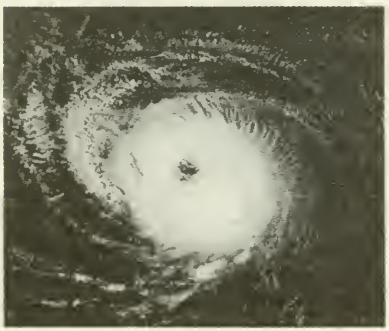
Will Sea Levels Rise?

We don't know. Some scientists believe that as we add carbon dioxide and other emissions to the atmosphere, the Earth will get warmer. If this happens, ocean levels may rise, because of melting ice and the expansion of ocean water as it warms. There is evidence of slowly rising sea levels over the last century, though the causes are not clear.

Rising ocean levels would make hurricanes and other storms more dangerous. More than half the U.S. population lives within 50 miles of a coastline. Some entire nations—like Bangeldesh and the Netherlands—are at or near sea level.



NASA's role: Using a form of radar, a U.S./French satellite is currently making the first precise measurements of global sea height. Data released last year shows a small rise in sea level since 1992, though more information is needed to establish a trend. Other measurements supported by NASA will examine how global ice sheets are changing. Over the next decade, all this data will help us tell whether the ocean levels are rising and, perhaps, if the Earth is warming.

NASA Facts

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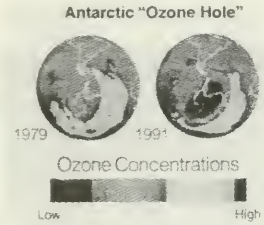
Is the Ozone Layer Still in Trouble?

Yes, but help is on the way. The ozone layer is a thin band in the upper atmosphere that blocks out most of the Sun's harmful ultraviolet rays. Without this protective shield, life on Earth would be impossible. The ozone layer has been damaged by chemicals (such as chlorofluorocarbons or CFCs) which are used in refrigerators, air conditioners and industry.

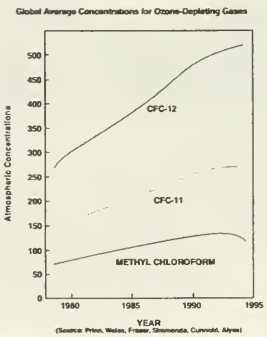
Ozone in Earth's Atmosphere

Stratosphere:
In this region, ozone is a shield It protects us from the Sun's harmful ultraviolet radiation
Troposphere:
In this region, ozone is a pollutant It damages lung tissue and plants
Earth
Mesosphere

NASA satellites, aircraft, balloon and ground measurements helped detect the effects of CFCs on the ozone layer and enabled us to understand why they were occurring. One of these effects is the "ozone hole," an area of extreme ozone depletion that forms over Antarctica each fall. As a result of this research—led by U.S. scientists, government, and industry—the nations of the world agreed to ban the production of CFCs by 1996.



NASA's role: While ozone levels over Antarctica and the rest of the globe will continue to decline for several years, NASA and NOAA measurements have now detected evidence that the treaties to protect the ozone layer are beginning to work. Concentrations of ozone-depleting chemicals are beginning to level off. Continued monitoring by NASA and other agencies and further study will be needed to understand how CFC substitutes are affecting ozone levels.



Facts on Mission to Planet Earth

ACCOMPLISHMENTS

RESEARCHERS

PROGRAM SCHEDULE AND CONTENT

EVOLUTION IN PROGRAM PLANNING AND BUDGET

Facts on Mission to Planet Earth: Accomplishments

Discoveries and Noted "Firsts"

Weather

NASA launched the first weather satellite (TIROS I) in 1960, beginning successful series of spacecraft that revolutionized weather prediction and improved hurricane-tracking techniques and severe storm warnings, thus protecting lives and property in coastal areas around the world. NASA continues to build all of America's civilian weather satellites.

Ozone

A NASA satellite instrument confirmed the existence of the Antarctic ozone hole in 1985 and has monitored its growth since then. Data from NASA aircraft, balloons, satellites and ground research helped confirm the link between human produced chemicals and ozone destruction. This research contributed significantly to the international treaties signed to protect the ozone layer. Now, NASA and NOAA measurements seem to indicate that the treaties are beginning to work.

Oceans

NASA ocean research provided the first precise measurements of ocean height and most precise data on ocean circulation to date. A NASA/French satellite helped determine the strength and duration of the 1994-95 El Niño, the latest episode of the climate shift that can bring devastating rains to the U.S. and drought to other parts of the world. In the future, these data will help us predict how El Niño will affect different regions. From 1978-86, a NASA instrument first provided global measurements of plant life productivity in the world's oceans (important to knowing both how climate may be changing and where fish are gathering); this data set will resume this year.

Land Surface

NASA pioneered studying the Earth's surface from space, spawning a growing commercial sector. NASA analyses of data from Landsat first proved that satellites could be used to accurately estimate tropical deforestation. These analyses revealed that the extent of deforestation in Brazil - while significant - was less than expected. NASA funded researchers are also using Landsat data to track the deterioration of wetlands in the Chesapeake Bay and fight diseases threatening the $10 billion California wine industry.

Earthquakes

Two NASA/Italian satellites have helped scientists precisely track movements of Earth's surface for nearly 20 years, increasing our understanding of earthquakes. NASA researchers also developed low-cost ground receivers that enable precise determination of land motion, another key in understanding seismic activity.

Facts on Mission to Planet Earth: Accomplishments
(continued)

Communicating Data and Research

Open Access

NASA leads the government effort to set an open access policy for the data from global change research. This means that all data from satellites is being processed as quickly as possible and made readily available for wide use. The prototype (Version 0) of the MTPE data system - called EOSDIS - came on line in 1994, allowing scientists around the world to work with existing data sets and to provide feedback to designers on how the system could evolve and be even more useful.

Broad Use

EOSDIS will be one of the largest civilian data systems ever constructed. While a major job will be to support MTPE scientists, NASA also estimates that EOSDIS will be used by:

- o Thousands of other scientists, in U.S. and across the globe
- o Up to 10,000 other researchers, government officials, etc.
- o Over 100,000 users in business, education, agriculture, media, and the public

Preparing for the Future

Education & Training

MTPE is helping train the next generation of scientists and engineers to understand and study Earth as an integrated system and educating and training educators as research evolves and capabilities change:

- o Awarded 282 global change fellowships since 1990
- o Supported 22 universities to develop college courses (introductory and upper level) in Earth system science
- o Helped develop an international science and education program - called GLOBE - in which thousands of U.S. and international students are making measurements and pooling data beginning this year
- o Sponsored a program of "ground truth" studies involving 946 teachers (and their classes) from 38 states and four countries since 1991
- o Educated teachers at 2,500 U.S. sites about MTPE science through NASA's live education videoconference series; 1995 efforts will discuss how we make information available and how we use radar to study Earth

Facts on Mission to Planet Earth

Researchers

Who are they?

1104 Research and Analysis investigators
541 Earth Observing System (EOS) investigators
1645 Total Mission to Planet Earth researchers

Where are they from?

1456 U.S. researchers from 45 states, the District of Columbia and Puerto Rico

- Nearly half from universities/colleges
- About a third from 6 NASA installations
- Remainder from private research centers and more than a dozen other government agencies

189 researchers from 13 other nations

What about the future?

NASA directly has awarded:
282 Global change graduate fellowships since 1990 (from 34 states & Puerto Rico)
62 NASA Graduate research fellows (Earth science) since 1989 (from 20 states)

NASA indirectly supports:
Thousands of graduate students assisting NASA-funded researchers at universities and laboratories across the U.S., developing the foundation for environmental research into the next century.

What do they do?

- Work on more than 1700 research tasks, in nearly a dozen research areas
- Help develop more than two dozen instruments for space flight over the next decade, and participate on 29 interdisciplinary science teams
- Lead and contribute to major international scientific assessments, including those examining the climate and ozone
- Produce upwards of 800 scientific papers annually on the results of their research

Facts on Mission to Planet Earth: Program Schedule and Content

NASA's Mission to Planet Earth seeks to improve our understanding of the complex interactions of Earth's environment, and how it is changing. The program has two stages: Phase 1, now underway, to make measurements of specific aspects of the Earth; and Phase 2, beginning in 1998, consisting primarily of the Earth Observing System (EOS). EOS satellites will make two dozen different measurements over at least 15 years to provide the first long-term, integrated observations of the global environment. These observations will help scientists understand how the Earth's land, air, water, and life interact and eventually should enable scientists to predict how the Earth's climate will change, rather than just describing its features. The EOS budget through 2000 has been reduced by 60% since original approval by Congress in 1990, though the most critical science measurements and capabilities have been preserved.

Phase 1: Primary Missions Through 1998

Mission (with planned Launch Date)	Area of Study
Earth Radiation Budget Satellite (1984)	Radiation budget, aerosols, ozone
Total Ozone Mapping Spectrometer (1978,91,95,96)	Ozone measurements (with Russia & Japan)
Upper Atmosphere Research Satellite (1991)	Upper atmospheric chemistry (with UK & Canada)
TOPEX/Poseidon (1992)	Ocean circulation and sea height (with France)
LAGEOS-2 (1992)	Crustal motion & Earth rotation (with Italy)
NASA Spacelab series (1990-94)	Shuttle experiments on the atmosphere, effects of the Sun, and surface vegetation (with Italy, Germany, Belgium, & France)
SeaWiFS (1995)	Ocean productivity (data purchase)
NASA Scatterometer (1996)	Ocean surface wind speed and direction (with Japan)
Tropical Rainfall Measuring Mission (1997)	Tropical rainfall and storms (with Japan)
Landsat-7 (1998)	Land surface features & changes (high resolution)

Phase 2: The Earth Observing System (measurement groupings)

Mission (with planned first Launch Date)	Area of Study
EOS-AM Series (1998)	Atmospheric/surface/solar processes controlling fresh water resources and ecological processes affecting global climate (with Japan and Canada)
EOS-PM Series (2000)	Causes of climate variations and basis for improvements in long term weather/climate prediction (with Europe)
EOS-Chemistry Series (2002) / SAGE (1998,2001)	Behavior of ozone, other greenhouse gases, and aerosols and their impact on global climate; also, regional and global studies of pollution (with Japan, UK and Russia)
EOS-Altimetry Series (1999,2003) / SeaWinds (1999)	Role of oceans and ocean winds in climate system and interaction with atmosphere (with France and Japan)
EOS-ACRIM Flights (1999)	Changes in total solar output (partner TBD)
EOS SOLSTICE Flights (2003)	Changes in ultraviolet radiation output from the Sun (with partner TBD)

May 3, 1995

Facts on Mission to Planet Earth: Program Schedule and Content
(continued)

Getting Information to People: The EOS Data and Information System (EOSDIS)

- EOSDIS is an integrated data system which provides users with access to data and information from NASA's Earth observation missions. The system is specifically designed to evolve and adapt to changes (in user applications, technology, and requirements) so as to best serve all current and prospective users (defined and undefined)

- EOSDIS is also a distributed system, with a central architecture (EOSDIS Core System) and a set of nine interconnected data centers (DAACs) across the U.S., each focusing on the processing, storage, and distribution of a different type of data about the Earth.

MTPE Distributed Active Archive Centers (DAACs)

Alaska SAR Facility (U. of Alaska)	Sea ice / polar processes
EROS Data Center (U.S. Geological Survey)	Land processes imagery
Goddard Space Flight Center (NASA)	Upper atmosphere, global biosphere, geophysics
Jet Propulsion Laboratory (Cal Tech)	Ocean circulation and air-sea interactions
Langley Research Center (NASA)	Solar radiation budget/aerosols /lower atmospheric chemistry
Marshall Space Flight Center (NASA)	Hydrologic (water) cycle
National Snow and Ice Data Center (U. of Colorado)	Non-radar ice imagery
Oak Ridge National Laboratory (DOE)	Biogeochemical dynamics
Socio-Economic Data & Applications Center (CIESIN)	Socio-economic data

MTPE Budget Information

- The largest budget element for Mission to Planet Earth is the Earth Observing System (EOS). Through 2000, NASA estimates the total cost of EOS will be approximately $7.6 billion. NASA's FY 1996 request for Mission to Planet Earth is almost identical to that approved for FY 1995.

FY 1995 approved funding and FY 1996 request (dollars in millions)

Program Element	FY 1995 Approved	FY 1996 Request
Earth Observing System (flight segment, including Landsat)	591.1	591.1
EOS Data and Information System (EOSDIS)	230.6	289.8
Applied Research and Data Analysis	344.3	308.4
MTPE Science	*[227.8]*	*[209.9]*
Operations, Data Retrieval, and Storage	*[116.5]*	*[98.5]*
Earth Probes (TOMS, NSCAT, TRMM)	81.6	36.9
Payloads and Instrument Development	19.5	4.9
Construction of Facilities	17.0	17.0
Launch Services	48.7	88.0
Other (GLOBE, ACTS)	7.3	5.0
TOTAL MTPE BUDGET	1340.1	1341.1

Facts on Mission to Planet Earth: Evolution in Program Planning and Budget

How has MTPE evolved?

o The Earth Observing System (EOS) was originally designed during the Reagan Administration to study the full range of issues associated with changes in the global environment. President Bush formally proposed to build EOS in 1990 and Congress approved a "new start" for the program later that year. Since 1990, EOS has undergone three restructuring efforts (in 1991, 1992, and 1994), designed to focus objectives and approaches and reduce the overall program budget.

Main results of EOS restructuring activities (1991-94)

- Reducing program focus to the highest priority issues associated with global climate change
- **Reducing program budget thru 2000 from $17 billion to $7.25 billion**
- Shifting from use of a few large spacecraft (6) to a greater number of smaller spacecraft (at least 27) over the 18 year life of the program
- Reducing the total number of measurements planned for flight from 30 to 24
- Increasing reliance on international cooperation through measurements made by international partners and flight of U.S. instruments on international spacecraft

o NASA is committed to further reducing the cost of implementing EOS, with the most promise being in the second (launches in 2004-2009) and third (launches in 2010-2014) phases of the program. We will do this through incorporation of new technology (incl. smaller satellites, instrumentation and subsystems, such as is expected from NASA's proposed New Millennium program) and stronger linkages with commercial, interagency, and international partners. This evolution is made possible by rapid advances in technology since our original planning for the program and by the prospect of forming partnerships with industry in the emerging area of commercial remote sensing. A study is now underway on this subject.

1995 MTPE Evolution Study

To prepare for program evolution, NASA initiated a study in March 1995 to examine innovative means of pursuing the second and third flights of the EOS measurements. as well as examining means by which technology could be infused into other MTPE satellites and into the national weather satellite program. This study will examine ways of reducing size, power, and processing requirements in making the measurements, while maintaining data continuity and integrity. It will also examine the role of the "common spacecraft", whose use as a common bus had been planned for both the first and second phases of EOS. It will run through this summer and develop a proactive strategy for implementing the next phases of the program.

May 3, 1995

Chairman WALKER. Mr. Mika?

STATEMENT OF MR. ARAM MIKA, HUGHES AIRCRAFT CORPORATION, EL SEGUNDO, CALIFORNIA

Mr. MIKA. Mr. Chairman, and distinguished members of the Committee, it is my privilege to be here today to offer some perspectives regarding the Mission to Planet Earth program.

In my remarks this morning, I would like to specifically address two topics.

One, the sizing of space systems. We've heard a lot of discussion about small, medium and large and I would like to speak to that issue.

And secondly, I would like to talk about the technology considerations associated with Mission to Planet Earth.

By way of context, these comments are based on our experience in designing and developing and launching 68 space-borne instruments over the last 30 years, that now have about 275 on-orbit years of operation.

There are four key messages that I would like to convey today.

First of all, the restructured Mission to Planet Earth program already represents a well-balanced design utilizing medium-size satellites for the core mission and smaller satellites for specialized measurements and technology demonstrations.

So through four iterations and series of reviews, it already represents a very well balanced program.

The second key point is the EOS spacecraft and instruments currently under development represent the technology state of the art in the early 1990s.

They thoroughly exploit NASA, DOD, commercial and other space technologies. Indeed, the contractor base developing these instruments and spacecraft are largely the same working on these other programs.

So they're fully exploiting the tools at hand.

The third point that I'd like to make is that the size and mass of payload instruments flow logically from the science- derived measurement and calibration requirements.

First, we ask ourselves what it is we wish to measure and then the scale follows from the physics and the technology.

These requirements have been established iteratively, interactively with the science community. In my experience, I cannot recall a program that has had better and tighter coordination with the science community from its inception. This dates back more than ten years.

The fourth key point I'd like to make is that small satellites do have a very promising future role for focused missions requiring specialized measurements from unique orbits and also as terrific vehicles for technology demonstrations.

I'd like to now briefly elaborate on these four key points, if I may. I shall begin with some of the top-level design considerations for establishing the sizing of Earth Observation Systems.

The sizing and architectural design of these systems is a very complex trade-off. The factors include the physics of measurement, economies of scale, data and communications strategies, storage

strategies, launch vehicle capabilities, and funding profiles, very significantly.

For Mission to Planet Earth, there is an additional overlay, and this is very important because it drives the design. And that overlay is that we need to make a broad variety of measurements of the Earth from space and these inevitably require a wide variety of payload instruments—imagers, sounders, atmospheric profiling instruments, spectrometers, radiometers of varying types.

So there's a panoply of instruments required to make the requisite set of measurements.

Inevitably, these instruments have different payload accommodation requirements. They consume different amounts of power, have different sizes that flow from the physics. They have different data rates. And this forms the germ of the issue as to why one size does not fit all if we try to propagate, say, a proliferation of small sats all exactly alike.

In fact, let me move to that topic. What about small sats?

Well, the dream of producing a large number of identical small spacecraft to achieve low-cost by economies of scale is going to prove elusive when we try to accommodate this wide variety of payloads.

What will happen is that if we go with a small common spacecraft, then the cost of customizing this spacecraft inevitably for each of these different instruments will incur some nonrecurring design cost.

On the other hand, if we try to design a small spacecraft to the highest common denominator, the greatest weight of one instrument, the greatest power of another, the highest data rate of another, then it will go to the point where we begin to lose the economies of this production line replication of a very low-cost system.

So this has been considered. But there are issues there associated with trying to solve it in that fashion.

What about large satellites?

Well, if we look at it strictly economically, if you say, what is the least expensive way to do this mission, one would probably be driven to a program that has many payload instruments on a relatively small number of large spacecraft.

Now the essence of the logic is as follows.

It is generally less expensive to incrementally enlarge spacecraft subsystems, like power, communication, propulsion, and so forth, than it is to replicate these systems repeatedly on a whole constellation of satellites. This logic is analogous to the idea that when you're carrying people to a certain destination, it's less expensive to put them all on a bus than to send them each in their private cars.

So if we were looking just at the economics, we would begin to concentrate. This creates a problem, however. If we were to do that, we would create a very fragile system where one launch failure could spell the end of the program. Further, launch costs at the very high end become nonlinearly high, so it does get more expensive once one is on to a Titan IV booster.

Also, and this has been duly noted, these become very complex. They have a long gestation period. That gestation period could be-

come so long that the technology could be nearly obsolete by the time the launch date arrives.

Looking at these various considerations, there's a very productive middle ground. And that is, medium-sized spacecraft that can be launched on Atlas Delta-class vehicles strike a very nice balance between the fragile, high-risk, few spacecraft program and the technology issues associated with the proliferated small sat program.

Indeed, this was the essence of the change in the 1991 review and represents the Mission to Planet Earth program today. And the trade-offs and conclusions remain valid today.

We must note, though, that it is important that the program have a workable vehicle for insertion of new high-risk, high-payoff technology.

In that regard, small sats provide a parallel avenue and they are ideal for that purpose, and we thoroughly embrace them.

I would note that NASA's restructured program has already embraced this approach. Dr. Kennel mentioned several of the programs, the small satellite technology initiative, the New Millennium program, the sea-viewing wide field sensors on a small sat.

So the program is already a hybrid that does embrace these.

I'd like to briefly turn now to——

Chairman WALKER. Mr. Mika?

Mr. MIKA. Yes, sir.

Chairman WALKER. I'm trying to keep time here and the five-minute clock ran out here about five minutes ago.

We're already losing members here in terms of being able to have a dialogue. So I would ask you if you could wrap up, and the other witnesses, if they could hold it to five minutes because I do want the members to be able to enter into this dialogue.

Mr. MIKA. Yes, sir.

Chairman WALKER. I appreciate it. Thank you.

Mr. MIKA. I shall move with dispatch to one other key punchline. And that is the issue of instrument technology.

I would like to emphasize that the spacecraft and instruments fully exploit the complete array of technologies. AM-1 is a very advanced spacecraft. It has solid- state recorders, graphite epoxy composites, microwave-integrated circuits, and so forth.

And the payload instruments, folks, are the current state of the art.

The point that I'd like to emphasize is that the contractor base is precisely the same that is working on the other programs. We have fully exploited the technologies available.

Folks, in the interest of time, I will wrap up. I would like to thank you very much for the privilege and I appreciate your time and courtesy.

[The prepared statement of Mr. Mika follows:]

STATEMENT

for

Hearing on the U.S. Global Change Research Program
and
Mission to Planet Earth

March 6, 1996

United States House of Representatives
COMMITTEE ON SCIENCE

Aram M. Mika

President
Space Electro-Optics Business Unit
Electro-Optical Systems
Hughes Aircraft Company

Introduction

Mr. Chairman and Distinguished Members of the Committee:

It is my privilege to be here today to offer some perspectives regarding the Mission to Planet Earth program. In my remarks, I would like to specifically address two topics: the sizing of space systems for earth-observation missions and the technology considerations associated with such missions. These remarks are based upon our experience in designing, developing and launching 68 spaceborne remote-sensing instruments of 21 different designs over the past 30 years. These instruments, ranging in mass from 2.1 kg to 370 kg, have successfully accumulated over 275 years of on-orbit operation for missions including earth observation, planetary science and meteorology.

There are four key messages that I would like to convey today:

- The restructured Mission to Planet Earth Program *already* represents a well-balanced design utilizing medium-sized spacecraft for the core mission and smaller satellites for specialized measurements and technology demonstrations.

- The EOS spacecraft and instruments presently under development represent the technology state of the art in the early 1990s for space-flight hardware. They thoroughly exploit available NASA, DoD and commercial space technologies.

- The size and mass of payload instruments flow logically from the science-derived measurement and calibration requirements, and these requirements have been established iteratively with the science community.

- Small satellites have a very promising future role for focused missions requiring specialized measurements from unique orbits and as vehicles for technology development and demonstration.

The following material offers highlights of the key points that substantiate these findings. I shall begin with the top-level design considerations that establish system architecture and spacecraft size in the context of an earth-observation mission.

System Sizing for Earth Observation Missions: Small, Medium or Large Spacecraft?

The architectural design and sizing of space systems is a complex tradeoff encompassing such factors as the physics of measurement, economies of scale, data communication & storage strategies, launch vehicle capacity & costs, and funding profiles & constraints. Additional considerations include frequency of coverage and revisit patterns. For Mission to Planet Earth, we begin with the need to make a broad variety of measurements of the earth from space -- measurements that inevitably require a number of different payload instruments including imaging sensors, radiometers, spectrometers, and temperature-sounding sensors, among others. In addressing all of these requirements and tradeoffs, one can envision an array of alternatives ranging from a proliferation of small satellites, each carrying an single payload instrument, to systems utilizing only one or two satellites, each carrying a full complement of sensors.

Small Satellites 100 kg to 750 kg (220 to 1650 lb)

The dream of producing large numbers of simple, identical small spacecraft to achieve low cost via economies of scale will prove elusive when trying to accommodate many different payload sensor designs of varying size, mass, power and data rate. In the limiting case, one can posit an architectural design that utilizes a constellation of small satellites, each carrying one instrument per spacecraft. With this approach, different payload-accommodation requirements for different payload instruments would either require tailored spacecraft designs for each instrument or a more capable 'common' smallsat designed to the highest common denominator. In the customized case, there would be significant nonrecurring development costs for each tailored spacecraft. In the 'common' case, the recurring costs would be relatively high since the spacecraft would have to accommodate the highest mass, power, data-rate and pointing-accuracy requirements found in the entire ensemble of payload-instrument specifications.

Large Satellites Over 5000 kg (Over 11000 lb)

From a strictly economic standpoint, the cost trades would favor a few relatively large spacecraft with many sensors aboard, for the same reason that a bus is a more economical solution for carrying a given number of people when compared to a proliferation of passenger cars carrying the same total number of people to the same destination. The essence of this reality is that it is inevitably less expensive to incrementally enlarge spacecraft structure, power, guidance and other subsystems on a single spacecraft, rather than to replicate all of the requisite subsystems (albeit on a smaller scale) for a proliferation of small satellites.

However, a one or two satellite approach would create a very fragile system of unacceptably high risk -- just one launch failure would spell the end of a such a program. Launch costs also increase nonlinearly for very large spacecraft. Moreover, the development schedule of multiple payload instruments and complexity of interfaces and sheer scale of the undertaking for very large platforms can lead to an unacceptably long gestation period -- a span of time so long that the technology employed could be obsolete by the launch date.

Medium-Sized Satellites 750 kg to 5000 kg (1650 lb to 11000 lb)

There is a productive middle ground, however, between the high cost of a proliferated smallsat system and the high risk of a system relying upon a few large spacecraft. Specifically, medium-sized spacecraft that can be launched on Atlas/Delta-class launch vehicles represent an excellent balance of cost and risk. Indeed, this was the essence of the outcome of the 1991 review of EOS, wherein the few large platforms sized for launch on the large Titan IV booster were subdivided into a number of medium-sized spacecraft that could be launched on Atlas/Delta class boosters -- spacecraft that are roughly in the same size class as the Landsat 4-5 series. This tradeoff and conclusion remain valid today.

The Mission to Planet Earth Program must also encompass a workable vehicle for the development and insertion of new high-risk, high-payoff technology. In this regard, a smallsat-based technology program would provide a parallel avenue for developing and demonstrating new sensor and spacecraft technologies in a fashion that does not jeopardize continuity of the operational data stream.

NASA's restructured program proposal has already embraced this approach, as demonstrated by their Small-Satellite Technology Initiative (SSTI), the Earth System Science Pathfinder (ESSP) and the New Millennium program. Note, however, that these programs could not reasonably be designed to serve as a substitute for the EOS AM/PM/Chemistry series of spacecraft. The cost and risk of developing entirely new instruments and spacecraft would surely increase the cost of the current EOS program. There is, however, a subset of science measurements for which smallsats would be very well suited: applications requiring measurements in tailored orbits or quick-response experiments to investigate a new class of measurements. Indeed, this approach was adopted following the EOS program restructuring of 1991, wherein Sea-Viewing Wide-Field Sensor (SeaWiFS) and the Active Cavity Radiometer Irradiance Monitor (ACRIM), two of the Mission to Planet Earth spacecraft that are part of the overall system architecture, are smallsats that are to be launched on the Pegasus vehicle.

Technology Considerations

Spacecraft and Instrument Technology

The spacecraft and instruments currently being built for EOS represent the technology state of the art in the early 1990s, and these designs have fully exploited the complete array of NASA, DoD and commercial technologies available. For example, the EOS-AM1 spacecraft presently under development utilizes subsystem technologies from DOD's most current satellites, as well as from the contractor's commercial communication satellite product line and from NASA scientific spacecraft, such as the Upper Atmospheric Research Satellite (UARS). For example, advanced technologies such as graphite-epoxy composites, solid-state recorders, microwave integrated circuits, solid-state transmitters, a capillary pump thermal system, precision pointing, and on-board spacecraft navigation have all been incorporated on the EOS-AM1 spacecraft.

As for payload instruments, the Moderate Resolution Imaging Spectrometer (MODIS), for example, is at the cutting edge of the state of the art in calibrated spectroradiometry, with many 'firsts,' including the first on-board spectral/spatial/radiometric calibration system. This instrument is being built by the same contractor that is developing the payload instruments for the Brilliant Eyes (Space and Missile Tracking System) program, and MODIS has leveraged tens of millions of dollars of DoD investment in advanced focal-plane technology, signal processing and materials, among others. Moreover, this instrument has been completely designed with state-of-the-art Computer-Aided Design tools that have permitted rapid design iterations to optimize size and mass. In short, the contractor base for EOS spacecraft and instruments is largely the same set that has been and is deeply involved in commercial, DoD and related programs, and they have applied the best tools and technology available.

Payload Instrument Sizing

The size, mass, power requirements and cost of EOS instruments flow logically from the measurement requirements that have been established by the science teams. Indeed, there is a straightforward process whereby the fundamental scientific questions to be answered lead, in turn, to a set of measurement requirements that establish the point of departure for sensor-design studies. These tradeoff studies address the design alternatives that can produce the required measurements, within the constraints set by fundamental physics, technology state-of-the-art, and cost. Within these bounds, designers work to minimize size, mass and power requirements. The process does not proceed in a vacuum: the engineers work iteratively with the scientific community to challenge requirements that are driving cost, size, mass and power so that science utility per dollar is effectively optimized; this is precisely the process that was used to develop the current suite of payload instruments. In short, size and mass flow from functionality, as illustrated below.

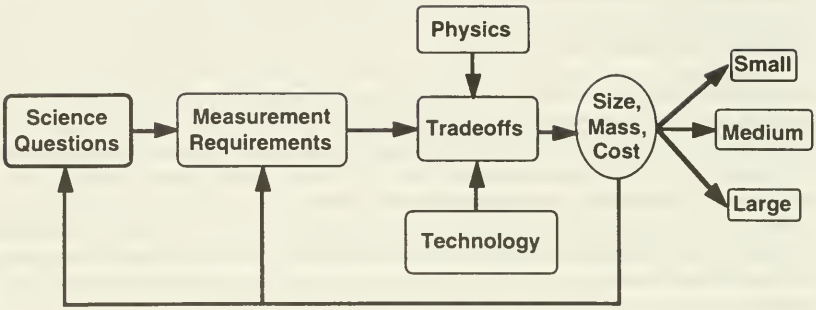


Figure 1. Size Follows Functionality

In the context of the present EOS instruments, the need for well *calibrated* measurements of great *radiometric fidelity* were design drivers that strongly influenced the size and mass of the instruments. There is a world of difference between instruments designed simply to produce an image to be viewed by a highly nonlinear and forgiving sensor -- the human eye, and between instruments designed to produce accurate, calibrated digital reflectance and emittance data that provide the basis for quantitative analysis of everything from ocean biomass and forest-canopy photosynthesis to lower atmosphere dynamics and chemistry.

Strategies for the Future: Technology Insertion and Data Continuity

Although the current EOS instruments are thoughtfully designed, continuing improvements in technology can and will influence the design tradeoffs, so there must be an effective mechanism for periodically revisiting these tradeoffs and incorporating new technologies that can enhance capability or reduce cost. This introduces a classic cost tradeoff: there are significant nonrecurring engineering costs associated with developing new instruments, so that the cost of developing the first of a series of new instruments is almost invariably higher than simply building another copy of an existing design. Yet, newer sensor designs could offer savings in total system cost, if size, mass and power reductions permit corresponding reductions in spacecraft and launch vehicle size -- but the design of the smaller spacecraft needed to realize these system-level savings requires another nonrecurring investment , and so it goes at many levels.

In essence, there are competing strategies for effecting economies. On the one hand, the most powerful economic strategy is to produce many copies of the same design, thereby deriving economies of scale from quantity production and amortization of nonrecurring development costs

over many units. On the other hand, advances in technology will eventually change the cost/capability equation enough to overwhelm the economies of scale. Accordingly, an effective strategy must balance these countervailing trends by embracing a methodical strategy that captures some economies of scale by producing several copies of a particular design, and then periodically introducing 'block changes' that exploit advances in technology -- perhaps on every second series of satellites. Indeed, this strategy has been used by other satellite programs, and its adoption is not accidental.

Data continuity introduces another dimension to the technology strategy. A stable set of well-calibrated, reliable measurements is central to the Global Change Research Program. Indeed, much effort has been expended to design instruments that will be stable enough to ensure that we are truly measuring changes in the earth and its environs, rather than instrument artifacts and instabilities. Introducing new instruments will undermine continuity and confidence in the measurements. Yet, there are serious problems in attempting to field a particular set of instruments in perpetuity. Technological obsolescence will eventually make it infeasible to even reproduce a given set of instruments due to diminishing availability of the specific components and skills that are associated with a particular design. Twenty years is probably the outside limit for any one design. In fact, some space instruments have been in 'production' for nearly this interval, but closer examination would reveal that they have been continually upgraded to surmount some of the parts availability problems cited above.

The complex challenge of technical renewal, while maintaining data continuity and quality, can best be addressed by embracing a concept that we might call *dynamic* continuity. Specifically, the quality and continuity of measurements must be transparent to three levels of changes:

- Between successive flights of the same instrument design
- Between successive generations of instruments
- Between similar instruments fielded by different countries

Dynamic continuity can be achieved via a strategy that encompasses a rigorous calibration program, utilizing both in-orbit and in-situ measurements, and the discipline to adopt an approach that ensures overlapping measurements between successive generations of instruments over a sufficient interval to ensure accurate cross-calibration. In many respects, NASA did this very well in the Landsat 4-5 era, where the new 'experimental' Thematic Mapper instrument was carried alongside the existing 'operational' Multispectral scanner.

This same basic approach can and should be carried forward as a technology insertion strategy, although it is not strictly necessary to carry the old and the new simultaneously on the same spacecraft. Indeed, smallsats become an ideal vehicle for the development and introduction of new technology in a fashion that does not introduce risk into the mainstream scientific-measurement

program. Specifically, new payload instruments, developed in parallel with EOS and flown on smallsats (perhaps in formation with the EOS spacecraft) would be an excellent approach for establishing the validity and intercomparability of the new and old measurements. This overlap also provides an opportunity to develop and prove the algorithms for reducing and analyzing the data from these new payloads and to provide an orderly transition as these experimental instruments, first flown on smallsats, become the next-generation mainline instruments on subsequent spacecraft.

Another powerful aspect of this approach is that it encourages pursuit of high-risk, high-payoff technologies. By conducting the development off-line without risk to an operational mission, fear of failure does not become an overriding principle that stifles innovation. Moreover, the development protocol for such technology demonstrations can be less formal and expensive -- a "skunk works" operation tailored to the needs of an experimental program.

Summary

The restructured Mission to Planet Earth Program already represents a well-balanced design utilizing medium-sized spacecraft for the core mission and smaller satellites for specialized measurements and technology demonstrations. With regard to technology, the EOS spacecraft and instruments presently under development represent the state of the art in the early 1990s for space-flight hardware. Indeed, the contractor base for EOS is simultaneously engaged in a wide variety of NASA, commercial and DoD programs, and they have thoroughly exploited the best of these technologies for benefit of EOS. Regarding the design of payload instruments, the size and mass of these sensors follow logically from the science-derived measurement and calibration requirements, and these requirements have been established iteratively with the science community. As we examine strategies for making new measurements and upgrading technology, small satellites have a very promising future role for focused missions requiring specialized measurements from unique orbits and as vehicles for technology development and demonstration.

Again, it has been my privilege to appear before the Committee today. Thank you for your time and courtesy.

Chairman WALKER. Thank you very much.

Dr. Castruccio?

Dr. CASTRUCCIO. Castruccio.

Chairman WALKER. Castruccio.

Dr. CASTRUCCIO. Right.

Chairman WALKER. Okay. I'm sorry. Thank you very much. We'll recognize you next.

STATEMENT OF DR. PETER CASTRUCCIO, ECOSYSTEMS INTERNATIONAL, INC., GAMBRILLS, MARYLAND

Dr. CASTRUCCIO. Thank you, Mr. Chairman. It's a pleasure to be here, despite the meteorology and the parking situation, the combination of the two.

Chairman WALKER. We're going to solve that with satellites some day.

Dr. CASTRUCCIO. Yes, we're going to solve that.

[Laughter.]

The name of the game here, the way I interpret your charges, Mr. Chairman, is how can we make it cheaper?

I will omit discussion of cheaper sensors because my colleague on the right is covering that. But I want to talk about simplifications and cost savings from methodologies.

Three points.

One, we might consider, or should consider, the operational use of surface data. I know surface data are now being gathered for calibration purposes. However, world-wide, we have on the surface approximately 250,000 sensors which work all the time in different countries and they are ground, sea, water, and air. Some of them have fairly long data streams gathered in the past decades.

The Nile is quoted at 5000 years. The others have less.

These sensors now exist and the beauty is they are paid for and the data is paid for by other countries. I don't want to confuse this type of sensor with gathering calibration data. They're two different things.

Now, these remote sensors of this type, such as buoys in the ocean, can be connected to existing space data collection systems like the GOES and the ARGOS. The ARGOS, for example, will charge 40 cents an hour—that's cents of a dollar—40 cents an hour to gather these data and relay them back to the user or the scientist.

The surface data thus gathered is robust. That means it measures really what happens—salinity, presence of algae, and so forth.

The space data rely on radiometric information, so they have to translate that information into what really happens. The two should be combined, in my opinion.

If you look at how data are gathered in the modern world, by institutions such as like USDA, USGS, National Weather Service, you'll find they're really all surface data, the satellite being as an adjunct to them.

Potential economic trade-offs—take the Mission TRMM, for example, Tropical Rainfall Measuring Mission. The cost of that mission could purchase 33,000 sophisticated ocean-going buoys—because that mission does mostly ocean, or 150,000 existing, less sophisticated buoys.

The questions are to what extent would these economical data satisfy science objectives? Our experience shows a considerable number of these ground systems can satisfy a lot of science objectives.

Now, what do they cost and what international exchange arrangements ought to be considered?

The second point is use of sampling techniques. At the present, the data gathering by agencies is practically all done by sampling. Sampling means simply we take a few points—a few may be 10, 20, 100—to represent a population.

For example, opinion sampling is not done over the entire population. It's done on a few thousand people using statistical techniques.

For example, the crop computation in the United States is done over less than one percent of the territory, little segments carefully chosen. Likewise, the weather is done by sampling.

And it's interesting to note that the sampling technique works everywhere. It works in Pennsylvania as well as in Albania, where recently, a survey was done to determine the crops using exporting sampling techniques developed by USDA.

Now, the space sensor—and then I'll be finished—space sensors really sample in time. In other words, they take a snapshot and return perhaps two days later. That's called a time sampling.

Surface sensors are fixed and sample in space. Can the two be combined to further the objectives of EOS?

The third point—utilization of scientists. Long experience shows one important fact. No scientists, with very few exceptions, no scientists will work on this program unless he gets paid. There's no such thing as a free lunch. And we must then take into account the considerable number of scientists which will be around until the end of the program.

It is in my experience fallacious, as was done in the past, to say, oh, well, once we got the data base, the world will beat a path to our door.

That will not happen.

We are all in favor of science, but we're also all in favor of making it affordable, making it reasonable.

Thank you.

[The prepared statement of Dr. Castruccio follows:]

Report on Mission to Planet Earth (MTPE) Earth Observation System (EOS)

Prepared at the request of:

The Committee on Science
US House of Representatives
Hearing of March 6, 1996

by

Dr. Peter A. Castruccio
Panel I

Members of Panel I were charged with "discussing different means of collecting data about the earth and its processes, with an eye towards exploring innovative and cost-effective methods".

Analysis of pertinent documentation, discussions with scientific and managerial personnel within and outside the EOS program, supported by this panelist's 30 year's involvement in remote sensing and earth resources programs, leads to certain observations and suggestions, aimed at reducing the program's costs and enhancing its effectiveness:

- Augment the operational use of surface-derived data. These are relatively inexpensive to obtain, and frequently more robust than space-derived data.

- Make as much as possible use of sampling techniques. It is not practically feasible, nor desirable, to "measure everything everywhere".

- Optimize the usage of scientific personnel involved in the program

1. Greater operational use of surface-derived data

Consider the operational exploitation of the archival data available from existing surface-based sensors (on land, oceans, atmosphere). These amount to approximately 250,000 installations that measure various phenomena: rain, temperature, streamflow, etc. Some of the data sequences generated by these sensor stretch backwards in time for decades (the Nile is quoted as having been gaged for the last 5,000 years). These data represent a considerable historical record, whose wise exploitation might reduce the need and/or costs for measurements from space.

In addition to archival data, continuous use is being made of this instrumentation in many nations. An important point is that the data are paid for by each host country. Current operational technology allows remotely sited ground-based instruments, e.g., raingages, streamflow gages, temperature sensors, to be outfitted with transmitters communicating with data-gathering satellites, whence the data can be relayed to earth-based collecting stations, thence to users. One such data collection and dissemination system is ARGOS, that charges on the order of 40 cents per hour, or $3,500 per year per sensor operating continuously full time. Another is GOES.

These considerations apply as well to open-sea measurements where instrumented buoys are currently used to measure oceanic parameters (temperature, salinity, seacurrents, waveheights etc.), and which transmit the collected data to spaceborne data collection and dissemination systems such as ARGOS.

Similar arguments apply to the numerous aircraft and balloon-based sensing programs, both past and ongoing in several countries, for example the massive program conducted in the US by USDA/ASCS and DOI/USGS, or NASA's excellent aircraft color infrared imagery program of the early '70s. Last but not least, consider the use of recently perfected UAVs (unmanned aerospace vehicles).

Good meteorological data are being generated by weather radars, in the US and in several foreign countries.

Surface measurements are by their nature more "close to the phenomena" than their space-borne counterparts, which generally rely on inferring the underlying mechanisms from intermediate parameters, mainly the characteristics of electromagnetic radiation emitted by or reflected from, the objects being looked at. Moreover, there are phenomena that cannot be sensed from space: for example, oceanic subsurface temperature.

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It is possible that some of EOS's scientific objectives can be satisfied purely by surface measurements, with the space segment serving to relay back the data, at significant reduction in cost.

An idea of the potential economic tradeoffs between space and surface measurements can be obtained considering for example that for the price of the TRMM mission one could purchase approximately 30,000 sophisticated multisensor buoys - enough to cover the surface of the earth's oceans with a density of one buoy for every degree of latitude and longitude. In the case of more economical buoys, such as those now employed by NOAA in the WOCE program more than 100,000 could be acquired and deployed.

To be sure, EOS researchers propose to use "all available data from whatever source". Perusal of the program however appears to indicate a trend towards using surface data more as ground truth for calibrating space sensors than in an integrated operational mode. In reality, most ongoing scientific and utilitarian data gathering program, in the US and alroad, employ surface data as the primary source, with space data as the supplement: in a sense, space data serve to calibrate and fill the gaps between ground data.

Key questions are: to what extent would the operational incorporation of surface-derived data satisfy EOS's scientific objectives? At what cost? What would it cost to upgrade obsolescent surface sensors, if and as needed? How many do we need? Do we need to densify their coverage in certain areas? What would this cost? What arrangements ought to be pursued to insure further international exchanges of these particular data?

2. Use of sampling techniques

Existing documentation plus discussion with EOS personnel appears to show a trend aimed at "measuring everything all the

time", which NASA defines as "continuity of observations". Yet, EOS spacecraft flying in LEO (Low Earth Orbit) do not really accomplish this. A satellite passes over a single given point in a matter of minutes, and returns over the same point some time later, depending on the sensor's swath width and satellite orbit. In other words, the satellite takes a series of "snapshots" of the conditions below, interleaved by relatively lengthy periods (up to some days) of absence of data.

Surface-based sensors on the other hand provide a complementary capability: they can collect data on a temporally continuous basis, but spaced geographically.

In other words, neither type of measurement is continuous: both are sampled. Spaceborne measurements are sampled in time, surface-based measurements are sampled in space.

This state of affairs suggests taking a look at a strategy that combines the strongest features of both modes of data gathering, with a view to reducing the data - gathering burden, hence the cost of the system.

Sampling techniques are widely used in operational, scientific, social, political data gathering programs because they significantly reduce the costs of collection and processing. For example, by USDA in assessing crop production, by the SCS (Soil Conservation Service) in estimating snow depth in Western mountains, by the NWS (National Weather System) in forecasting the weather - by pollsters in opinion-sounding surveys, and so forth.

An example of a sampling scheme is offered by the "biological explosion" warning system developed by my company to forecast potential algal blooms (deleterious to the tourist trade) in the upper Adriatic. Beginning in mid-June, a limited number of motorboats stop at specified sites, where they take measurements on

sea parameters harbingers of potential algal growth: dissolved nitrogen, phosphorous, surface and subsurface temperature, currents, algal type and density, etc. The boat's position is determined from GPS. The measurements are processed on shore into a "probability" map for use by the "clean up" authorities.

Some of the above measurements cannot be accomplished by remote sensing: the "trigger" dosages of nitrogen and phosphorous are tiny, accurate subsurface temperature is still beyond our capabilities. On the other hand, it would be costly to expand the system to a world-wide scale, covering the oceans with instrumented motorboats. In this case, a two-level sampling scheme could be employed. From past (archival) data, we know that algal blooms tend to occur in certain areas, e.g. Florida's east coast, Bangladesh. These areas could be monitored by a system of the type just described. From satellites, as happened in the Adriatic, one can discern the bloom--but, only while it is occurring, generally too late for preventive remedial action. However, each new occurrence would spot the area where future surface - monitoring activities might be undertaken. In other words, the satellite would sense that a change has occurred--for further investigation by a surface system.

3. Use of program scientists

Experience shows that scientists will utilize the program's data only if they are paid. In other words, one ought not to expect a large number of external scientific users beating a path to EOS's door--unless somebody funds them. Since the program is aimed at "pure science", this somebody will most likely have to be the government, either directly or through the intermediary of academic institutions--in either case, with taxpayer's moneys.

In other words, we ought not to expect free aid and succor from the scientific community at large, whether domestic or foreign-academic institutions con ill afford it.

It may be prudent in this context to consider generating a certain aliquot of operational products or of the data that form the ingredients thereof, for further elaboration by the users, directly or through added-value operatory. Such products might be offered for sale to private industry--for example, fishing models, crop forecast models, highly accurate local weather forecasts for use by the tourist industry.

In summary, careful consideration ought to be given to the near-and long-term structure, evolution and funding of the scientific group serving the program.

Mrs. MORELLA. [presiding] Thank you, Dr. Castruccio.
Dr. Ledebuhr, let's hear from you.

STATEMENT OF DR. ARNO LEDEBUHR, LAWRENCE LIVERMORE NATIONAL LABORATORY, LIVERMORE, CALIFORNIA

Dr. LEDEBUHR. Good morning, Mr. Chairman, and members of the Committee.

I'm Arno Ledebuhr, a senior scientist at Lawrence Livermore National Lab, and currently the project leader for the laboratory's portion of the Clementine II mission. We're developing impactor probes and sensors for this Air Force sponsored project.

For nine years I've been responsible for advanced sensor development, including the Clementine I sensor suite.

I welcome the opportunity to provide testimony on some of the space-based remote sensing technologies and system concepts that we have developed at Livermore over the last decade. It is our premise that by the turn of the century, using today's technologies, the constellation of several dozen small satellites can be rapidly developed that could provide valuable remote sensing capabilities to support the U.S. Global Change Research Program.

With continued production and technical enhancements, this constellation could affordably grow to a few hundred platforms in just a few years, providing robust dual-use civilian and military global data collection system.

Beginning in the mid-'80s, our efforts at Livermore were focused on the development of advanced configurations of state-of-the-art commercial technologies for miniaturized space sensors and space-based interceptor systems.

In these developments, we employed a system of engineering approach that generated integrated modular designs with functional sharing of subsystems. This work resulted in large reductions in size, mass and power requirements at lower cost, while increasing overall system performance levels.

We've worked to space qualify, for example, commercial electronic components using plastic packaging versus conventional ceramic.

Our development strategy has also incorporated a build-a-little, test-a-little approach to quickly move through the development cycle and employed innovative hardware and in-the- loop testing.

On July 24th, 1991, I presented a program proposal to the Earth Observing System Engineering Review Advisory Committee, chaired by Dr. Ed Frieman, titled, "Brilliant Eyes: A Pathfinder for EOS." This proposal articulated a concept first conceived by Dr. Edward Teller for a distributed constellation of small sensor platforms termed "Brilliant Eyes" for a distributed constellation to provide a comprehensive global remote sensing at high spatial and temporal sampling frequencies which would provide a dual-use capability for both civilians and military.

Our proposal called for ten satellites in orbit by mid-1995.

In 1991, there was considerable skepticism that DOD sensor technologies could collect scientifically useful data from small spacecraft platforms.

It's our technical assessment that the size of the instrument or observation platform has little correlation to either the scientific

quality or validity of the measurements. But, rather, it's the quality and stability of the calibration of the instrument that matters.

At this time, we documented the maturing technology suite that could provide this technical capability to implement this pathfinder concept.

Although the Brilliant Eyes pathfinder was not pursued by NASA, BMDO sponsored the Clementine Mission to demonstrate and space-qualify new advanced technology sensors and spacecraft component technologies.

Clementine incorporated 23 advanced DOD-sponsored subsystem technologies and carried an advanced suite of six multi-spectral cameras developed by the laboratory. The sensor suite weighed only 16 pounds and collected over 1.7 million images during its two months in lunar orbit, at a mission cost of less than $100 million.

The program schedule ran only 22 months from start to launch. The program set a benchmark as an extremely cost-effective mission for the quality and quantity of data collected. The data collected has enabled the global mapping of the rock types of the lunar crust and the first detailed investigation of the geology of the lunar polar regions and the far lunar side.

In addition, laser-ranging measurements provided the first view of the global topographic figure of the moon.

Clementine demonstrated that small satellites incorporating state-of-the-art sensor and spacecraft technologies can generate scientifically-useful data at affordable cost.

Competition in the consumer electronics market has continued to drive technology development. Examples include commercial microprocessors, video camcorders, and cellular phones, all of which show a continuing reduction in size, mass, power and cost, while increasing performance and capability.

Advanced spectral decomposition techniques enable imaging spectrometer science instruments to occupy the same volume as a typical imaging camera. These developments will enable even microsatellites weighing 50 pounds to carry out sophisticated imaging missions with little or no compromise in scientific quality.

The smaller size and corresponding lower production costs of a few million dollars per micro-sat make it practical to consider their use in large constellations of hundreds of platforms.

The commercial sector has already identified the utility of a distributed satellite constellation for global communications applications. Iridium will have 66 satellites for global cell phone coverage anywhere on the planet, basically implying that every point in the earth is visible from this constellation.

Unfortunately, it will not contain any imaging instruments. If it did, this constellation would allow simultaneous snapshots of the entire planet at very high resolution.

Several companies, including EarthWatch, Eyeglass, and Space Imaging, are actively engaged in the development of small satellites for high-resolution imaging, but they're not considering, at the moment, large constellations.

The availability of small commercial satellites buses provides an opportunity to affordably test new specialized scientific instruments cost effectively in a proof of principle demonstration. The constellation of small sats of the type discussed in this presentation

can effectively support the U.S. Global Change Research Program and have dual-use capabilities. Applications can range from monitoring weather, crops and pollution, to verifying military force build-up and supporting ballistic missile launch detection and tracking.

When the entire planet could be brought under near continuous observation in both high spectral and spatial resolution, this capability will generate many previously unrealizable opportunities and new applications which will have far ranging consequences for the foreseeable future.

Clementine demonstrated that small satellites incorporating state-of-the-art sensors in spacecraft can generate this data.

Thank you.

[The prepared statement of Dr. Ledebuhr follows:]

TESTIMONY
ON
SMALL SATELLITE REMOTE SENSING TECHNOLOGIES

Hearing: U.S. Global Change Research Programs: Data Collection and Scientific Priorities

Committee on Science
U.S. House of Representatives

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Introduction

I am Arno Ledebuhr, a senior staff member at the Lawrence Livermore National Laboratory. I am the project leader for the impactor probe development on the Air Force-sponsored Clementine II project. Previously, I was responsible for advanced sensor developments including, the sensors flown in the Clementine I mission.

I welcome the opportunity to provide testimony on some of the spacebased remote sensing technologies and system concepts that we have developed at Livermore over the last decade. I will discuss how remote sensing with small satellites (smallsats) can effectively support the U.S. Global Change Research Programs: data collection and scientific priorities.

I will first outline some of what we have learned and the approaches taken, in the development of lightweight, high performing sensors and interceptor systems. Beginning in the mid '80's, our efforts at LLNL were focused on the development of advanced configurations of state-of-the-art commercial technologies for miniaturized space sensors and spacebased interceptor systems. In these developments we approached our sensor system designs and interceptor vehicles from a system engineering perspective, producing integrated modular designs with functional sharing of subsystems. This approach has resulted in extensive reductions in size,

mass and power requirements, and has lowered costs, while increasing overall system performance levels. Our development strategy has also incorporated the "build a little, test a little" approach to iteratively and rapidly move through the development cycle.

This is in contrast to more traditional spacecraft design approaches in which the individual instruments are designed separately from the platform which carries them. LLNL has also pioneered the use of commercial electronic components to lower costs, and has demonstrated through extensive testing, their survivability in harsh space environments. This approach has been quite effective in space qualifying commercial electronics in "plastic" packages versus the traditional exclusive use of ceramic packaging. Following our successful demonstration, of several interceptor subsystems and integrated vehicle designs, through extensive ground and flight testing, our Department of Defense sponsor proposed that we apply our development approach for the benefit of both civilian and defense objectives.

Brilliant Eyes: A Pathfinder For EOS

On July 24, 1991 I presented a program proposal to the Earth Observing System (EOS) Engineering Review Advisory Committee, chaired by Dr. Ed Frieman, titled "Brilliant Eyes: A Pathfinder For EOS". This proposal articulated a concept first conceived by Dr. Edward Teller for a distributed constellation of small sensor platforms termed "Brilliant Eyes" that would be used to provide comprehensive global remote sensing at high spatial and temporal sampling frequencies and provide a dual-use capability for both civilian and military applications.

Our Brilliant Eyes (EOS) proposal discussed how a constellation of small satellites in the 90 to 200 kg mass class (200 to 450 pounds), flying a suite of miniaturized instruments, could be used as a pathfinder to NASA's Mission to Planet Earth(MTPE)/EOS. At that time EOS-A was a single spacecraft which was not scheduled to fly until the end of the decade. However, there was considerable interest in the scientific community to start gathering global change data to identify trends as early in the decade as possible, well ahead of the scheduled time for EOS to go on-line.

Our proposal called for replicating an instrument suite that would be functionality equivalent to the core instrument group that had been recommended by the National Research Council. These instruments included, a High Resolution Imaging Spectrometer (HIRIS) , a Moderate-Resolution Imaging Spectroradiometer (MODIS), a Clouds and Earth's Radiant Energy System (CERES), an Earth Observing Scanning Polarimeter

(EOSP), a Multi-Angle Imaging SpectroRadiometer (MISR) and the Atmospheric Infrared Sounder (AIRS). Several other instruments were also included, a Light Detection and Ranging (LIDAR) system, an Active Cavity Radiometer Irradiance Monitor (ACRIM) and the Stratospheric Aerosol and Gas Experiment (SAGE). HIRIS has since been dropped by EOS, but the remaining instruments along with many others are scheduled to be flown on several different spacecraft platforms as part of EOS.

The Brilliant Eyes (EOS) proposed constellation required four identical platforms to match the functionality of one EOS-A spacecraft. In this architecture one platform was placed in a near-polar orbit and three spacecraft were placed at a 60-degree inclination. The proposal called for placing 10 platforms in-orbit on a single launch (placing 8 birds at 60 degrees and 2 in near-polar orbits) to provide a two-fold functional redundancy. The program plan scheduled a 36 month development effort with an on-orbit cost of $370M. An option was also included that enabled increasing the total size of the constellation to 30 spacecraft. The Brilliant Eyes (EOS) approach would have quickly allowed the United States to have an interim satellite constellation on-orbit by late-1995 that would now be generating an EOS quality global data-set on the environmental state of the planet. This proposal did not receive any funding from NASA and the idea was dropped.

Distributed Remote Sensing

In examining the trade-offs in using multiple platforms to carry out the remote sensing mission required for EOS, several observational advantages become apparent. These include the reduction in revisit times, as well as, the ability to carryout multiple simultaneous observations of single target areas or provide global snap shots of the entire planet. This multiple platform system architecture approach adds both a robustness and redundancy to the measurements and results in unique capabilities a single platform cannot achieve. We observed that with the uncertainties that exist between the various spatial and temporal scale factors that lead to global climate patterns, high revisit rates and global simultaneity of observations may be both useful and ultimately needed to completely understand all of the processes involved.

In 1991 there existed considerable skepticism that DoD sensor technologies could collect scientifically useful data from small spacecraft platforms. It was our technical assessment that the small size of the observation platform and instruments had little correlation to either the scientific quality or validity of the measurements. At that time, we documented the maturing technology suite that could provide the technical capability to

implement this smallsat constellation. Since 1991 the techbase has continued to mature and additional enabling technologies have been demonstrated that reinforce the original thesis, that:

"Many of the important EOS-A science functions can be performed with a constellation of Brilliant Eyes LightSats oriented as a pathfinder to the EOS mission: Brilliant Eyes (EOS) - fast, cheap and effective"

Clementine Mission

Although the Brilliant Eyes pathfinder proposal was not pursued by NASA, DoD through the Ballistic Missile Defense Organization, sponsored the Clementine Deep Space Experiment, to demonstrate and space qualify new advanced technology sensors and spacecraft component technologies. Clementine carried an advanced multi-spectral electro-optic sensor suite, which included an ultraviolet-visible camera, a short wave infrared sensor, a long wave infrared sensor, an imaging LIDAR (Light Detection And Ranging) instrument and two Star Tracker cameras. This sensor suite weighed only 16 pounds and spanned a wavelength range of 0.3 to 9.5 microns. It successfully mapped the entire lunar surface in eleven spectral bands and generated a topographical data set using the laser ranging capability of the LIDAR instrument.

The Clementine spacecraft incorporated 23 advanced DoD developed subsystem technologies, including a high performance 32-bit RISC processor (R3081), a 2 gigabit solid state recorder, light-weight common pressure vessel rechargeable batteries, two inertial measurement units (a laser ring gyro and interferometric fiber optic gyro) and the thinnest (5.5 mils thick) gallium arsenide on germanium solar arrays yet flown. The spacecraft itself was fully 3-axis stabilized and incorporated gimbaled solar arrays, a monopropellant propulsion system for attitude control, a bipropellant propulsion system for maneuvering and light weight momentum wheels for fine pointing. The spacecraft contained composite structural elements and had a fueled mass of 1000 pounds and a dry mass of 500 pounds.

The instrument suite flown on Clementine used state-of-art component technologies from the late eighties and early nineties that were derived from our spacebased interceptor development program. The original remote sensing functions for these sensors concentrated on applications supporting spacebased surveillance, such as, missile launch detection, tracking and typing. Spacebased interceptor functions included autonomous attitude determination, multi-spectral imaging for plume-to-hardbody hand-off and terminal-homing using active imaging LIDAR

systems. By a careful selection of spectral filters and comprehensive sensor calibration, it was possible to turn the designs for these targeting sensors into a set of science instruments that has provided the most comprehensive data set on a planetary body to date.

The Clementine mission collected over 1.7 million images during its two months in lunar polar orbit at a mission cost of less than $100 million. This program sets a benchmark as an extremely cost effective mission for the quality and quantity of data collected. The data has enabled the global mapping of the rock types of the lunar crust and the first detailed investigation of the geology of the lunar polar regions and the lunar far side. In addition, laser-ranging measurements provided the first view of the global topographic figure of the moon. The topography of many ancient impact basins has been measured, and a global map of the thickness of the lunar crust has been derived from the topography and gravity.

Clementine's program management style was streamlined with minimal overhead and infrastructure to support the very lean and mean project teams. The program's cost and schedule were fixed from project start and these were closely monitored to track compliance. This approach significantly reduced both cost and schedule without compromising the scientific and engineering yield. The program schedule ran only 22 months from start to launch. Clementine demonstrated that small satellites incorporating state-of-the-art sensor and spacecraft bus technologies can generate scientifically useful data at affordable costs. Using techniques derived from spacebased interceptor development efforts the Clementine spacecraft was also able to demonstrate autonomous operations in a small spacecraft configuration. It is our contention that the technologies, system engineering approach, and advanced component testing demonstrated in this mission could quickly and affordably be applied to earth monitoring applications. This capability could provide the USGCRP with both an interim data set to better establish long term global change trends, as well as, generate a global monitoring system with high revisit capability that would support a wide range of both civilian and military applications.

Remote Sensing Microsatellite Constellations

Today's technology will enable smaller and more capable sensor systems and platforms than demonstrated in the Clementine mission. Commercial consumer electronics product development competition continues to drive down the size, mass and power of key subsystem technologies while increasing the performance envelope of these systems. Examples include

the commercial Power PC and Pentium processors which operate at over an order of magnitude faster processing speed and throughput than the leading RISC processors of a decade ago. These improvements in processing power and capability will afford small satellite platforms the ability to carryout various on-board data processing functions that will help reduce the volume of data that will need to be transmitted to the ground. Reductions in the size, mass and power of video camcorders and cellular phones are further examples of how these commercial sector technology developments can provide greater capabilities in smaller packages.

Advanced spectral decomposition techniques enable imaging spectrometer instruments to occupy no more volume than typical imaging cameras. These developments will enable even microsatellites in the 20 kg mass range (<50 pounds) to carryout sophisticated imaging missions with little to no compromise in scientific quality. The small size and correspondingly lower production costs (a few million dollars per unit) of these microsatellites, make it truly practical to consider their use in relatively large sized satellite constellations of hundreds to thousands of platforms. Last March, Dr. Edward Teller, in related testimony, outlined how a large satellite constellation of one thousand platforms could continuously monitor the global weather patterns with high spatial and temporal fidelity, enabling global weather predictions to be extended from their current five days out to two weeks. This level of global weather forecasting would have a significant economic benefit to this nation, as well as, a humanitarian benefit to the world population in general.

Commercial Satellite Constellations

The commercial sector has already identified the utility of the concept of a distributed satellite constellation for global communications applications and there are presently several systems under initial development. Iridium's constellation of 66 satellites is the farthest along, and is expected to be operational in late 1998. This constellation will provide a global cellular phone system that will enable point-to-point communication anywhere on the planet. Iridium incorporates RF crosslinks that interconnect the constellation and enable rapid tasking within and rapid transfer of data across the constellation. With only 66 satellites (at a nominal 750 km orbital altitude) every point on the planet is continuously in view of one of the satellites in the constellation. If these satellites contained imaging sensors, any point on the planet could be kept under continuous observation 24 hours a day at relatively high spatial resolution (a few meters). Since this large constellation has no imaging sensors, it will be left to some other system to provide this capability.

Several commercial enterprises are actively engaged in the development of small satellites for imaging remote sensing applications. Much of the satellite bus technologies under development in these programs are applicable to smallsats for EOS missions. Over time if there is a market and dedicated customer base these firms could modify their sensor systems and data products to accommodate the needs of the MTPE/EOS, but it is likely that this will only occur late in the next decade. With government sponsorship of a Clementine-like Brilliant Eyes (EOS) development program, several microsat/smallsat prototypes could be rapidly developed and operationally tested well before the end of this decade. Following the successful demonstration of the scientific utility of these prototypes their design would be transferred to the private sector for a production run and initial deployment.

Data Distribution

In addition, to the space segment, advanced distributed data handling concepts can be employed to provide quick access and rapid dissemination of the collected data. Following the Clementine mission, thousands of images were quickly placed on the internet as part of the LLNL's Science Education Program sponsored by the Department of Energy. The entire collection of nearly 2 million images was also placed on a small library of compact (optical) disks which has been distributed to NASA's Planetary Data System, a nationwide repository system for data returned from lunar and planetary flight projects. This data base is now widely available to lunar and planetary scientists.

Conclusions

With a focused development approach the nation could have on-orbit, an operational constellation of several dozen general purpose remote sensing microsatellites or smallsats, by the turn of the century. With continued production and technical enhancements this constellation could affordably grow to a few hundred platforms in a few years, providing a robust dual-use civilian and military global data collection system. As demonstrated in the case of the Iridium constellation, even a relatively small constellation of only 66 platforms, can provide continuous coverage of target areas anywhere on the planet. These high revisit times will lead to qualitatively new mission capabilities that never before were possible. A multi-satellite constellation of the type discussed above can easily support the USGCRP and be extended for use in monitoring crop yields and pollution rates, to verifying military force build-up and supporting ballistic missile launch detection and tracking. When thousands of points on the planet can be brought under near continuous observation in both high spatial and

spectral resolution, this capability will generate many heretofore unrealizable opportunities and new applications which will have far reaching consequences for the foreseeable future.

We as a nation are at a unique cross roads in history, in that we have both the means and the way to generate a new class of remote sensing systems that would afford us the ability to assume a leadership role in global stewardship, well into the next century. With Clementine we have demonstrated that our nation has the necessary technological means and using the "faster, cheaper, better" development approach can easily afford the cost to do so. Thank you.

Chairman WALKER. Thank you.
Dr. Christensen?

STATEMENT OF DR. ERIC CHRISTENSEN, EARTH WATCH, INC., LONGMONT, COLORADO

Dr. CHRISTENSEN. Thank you, Mr. Chairman.

I'm with EarthWatch, Incorporated. And one of the reasons that we're here today is because of the efforts of yourself and Mr. Brown over the years in establishing the legislation that helped create the commercial remote-sensing market.

I'd like to take a few minutes to describe our company and our programs and how it might relate to the subject we're talking about today.

As you know, EarthWatch is one of several commercial remote-sensing companies created since the Land Remote Sensing Act.

This summer, EarthWatch will launch the first commercial high spatial resolution remote sensing satellite called EarlyBird. A year later, our QuickBird satellites will provide the highest spatial resolution satellite imagery commercially available—that is, one meter panchromatic and four meter multi-spectral.

Within the next 24 months, our goal is to have two EarlyBird and two QuickBird satellites in orbit. All four will provide full global coverage and have access to the same geographic areas several times each day, more than any other system.

Although my testimony will focus on EarthWatch, our international partners and investors, including Ball Aerospace, Hitachi, CTA, MacDonald, Dettwilerr, Datron, and other venture capitalists believe that we're at the forefront of a commercially-driven U.S. earth imaging industry that could literally revolutionize how satellite imagery is used by both the private and public sectors.

Consider the fact that high spatial resolution, multi-spectral imagery collected from space is clear enough to distinguish cars, painted lines on streets and highways, chalk lines on tennis courts.

We can see damage to trees and crops not visible from the ground or to the naked eye, anywhere on the planet, each day, and can be supplied to the desk-top computer within hours after collection.

The earth imaging market right now is driven by the $6 billion geographic information systems industry, growing at about 14 percent per year. We estimate that the current imagery market is about $2 billion annually and could double within the next decade with the introduction of these new high spatial resolution satellites.

To date, several hundred million dollars have been pledged by U.S. firms for satellites and ground stations. The entire EarthWatch constellation of four satellites, four ground stations and other facilities will cost less than $200 million.

In terms of environmental applications, we see this as one of our biggest markets.

We have designed our satellites with the capability to serve a wide variety of environmental applications, from state and local regulation and regulators to global researchers.

The satellites have the ability to monitor changes over both large and small areas, from thousands of square kilometers to just a few square meters.

On a micro-scale, the imagery can be used to monitor water pollution discharges, hazardous waste activities, forest fire damage, illegal logging, and many others.

On a macro-scale, EarthWatch imagery can potentially contribute to three areas of global change research, including atmosphere, in terms of cloud cover, volcanic activity, oceans and land in terms of deforestation, urbanization, the effects of natural disaster like hurricanes, floods, earthquakes, et cetera.

We have designed our satellites to collect and deliver imagery in the most economical form, using off-the-shelf technologies, but at the same time maintaining spectral continuity with existing satellite systems.

EarlyBird has the same spectral bands as France's Spot satellite. QuickBird captures four of the bands found on Landsat Thematic Mapper.

Even though we are designing and building our own satellites, EarthWatch is essentially in the information business. As a result, EarthWatch has developed a unique network for acquiring, archiving, and distributing its satellite imagery. Called Digital Globe, it is a world-wide geographically referenced database of imagery and information products from EarthWatch and other sources.

The idea behind Digital Globe is that a customer can use the online Internet service to purchase imagery and information of just the area they need and have it electronically delivered to their desk-tops.

From the standpoint of the government user, we believe there are several benefits to using private data-providers.

First of all, the government capital is not at risk if the satellite fails. In effect, the government is leveraging private-sector capital, allowing the private sector to take the risks to meet public-sector information needs.

The government incurs no major operations or overhead costs since the private sector just provides the products, as opposed to handing over satellites and letting the government operate them.

The data products can be provided at an affordable price since the development costs can be spread over a large customer base. The customer can buy as much or as little as they want.

Now, typically, if government funding is cut, programs are either cancelled or schedules slipped. Instead, government customers have the option of simply buying less data.

At present, we have not identified a strong commercial market for scientific data, so it's not a part of our current product offering. On the other hand, the cost to EarthWatch of including a capability to collect data of scientific interest is probably not large.

For example, we currently perform ground-based calibration on our sensors, instead of absolute calibration on orbit. This is preferred by science missions.

The reason we don't do it, it's just not cost effective.

However, if a paying customer requested it, we could incorporate on-orbit absolute calibration in our future spacecraft.

Unlike many of our competitors, EarthWatch business does not depend on substantial U.S. Government procurements. On the other hand, we believe that innovative strategies for structuring partnerships between the government and commercial earth-imaging sector offers major advantages to both, especially in this fiscally-constrained climate.

In that regard, Mr. Chairman, we applaud the legislative language proposed by this Committee that calls on NASA to buy remote sensing data and services from the U.S. private sector, as well as study whether scientific requirements of Mission to Planet Earth can be met by the private sector.

It only seems appropriate that the government primarily responsible for the advanced lightweight satellite technology enabling EarthWatch's business opportunity investigate possible cost savings to its own programs by working with the emerging industry the U.S. Government helped create.

One final consideration.

Commercial remote-sensing imagery will be available and distribution systems such as Digital Globe operational years before EOS and EOSDIS come on line. Commercial imagery could potentially bridge the gap until the Mission to Planet Earth systems are deployed by accelerating the process of creating a global data base which in turn could begin contributing to effective environmental decision-making much sooner than currently envisioned.

Thank you, Mr. Chairman.

[The prepared statement of Dr. Christensen follows:]

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Dr. Eric Christensen
Director, Government Marketing
EarthWatch, Inc.
Committee on Science
U.S. House of Representatives

March 6, 1996

As you know, Mr. Chairman, EarthWatch is one of several commercial earth imaging companies that have been established in the wake of the 1992 Land Remote Sensing Policy Act. This summer, we will launch the first commercial, high spatial resolution, remote sensing satellite, called EarlyBird.

Our EarlyBird satellites will capture images with a ground sampling distance of 3 meters. A year later, our QuickBird satellites will provide the highest spatial resolution satellite imagery available commercially: 1 meter panchromatic and 4 meter multispectral.

Within the next 24 months, Mr. Chairman, our goal is to have our 2 EarlyBird and 2 QuickBird satellites in orbit. All four will provide full global coverage and has access to some geographical areas several time each day -- more than any other system. The EarlyBird 3 meter satellite will be placed in near-polar orbit, providing global coverage and returning to equatorial locations every 60 hours. The QuickBird 1 meter satellites will be placed in a high-inclination, non-polar orbit, frequently revisiting the planet's most densely developed land masses. Frequent revisit by commercial systems offers unparalleled flexibility and opportunities to evaluate and confirm short term change phenomena (daily and weekly), as well as acquire imagery under optimum conditions (no clouds, better illumination).

To date, several hundred million dollars have been pledged by US firms for satellite and associated ground systems. In the specific case of EarthWatch, we are entirely funded by private investment and do not rely on government subsidies. The entire EarthWatch constellation of 4 satellites, 4 ground stations, production, sales and distribution facilities cost less than $200 million. In contrast, our foreign competitors in Canada, France, Russia, India and Japan have spent billions of dollars of government funds building, launching, and operating their so-called "commercial" remote sensing satellites.

We are pleased to participate in this important and timely hearing and to provide the Committee some insight into the data acquisition and distribution capabilities being developed by our company. Although my testimony will focus on EarthWatch's activities, our partners and investors believe that we are in the vanguard of a commercially-driven U.S. space imaging industry that could literally revolutionize how spatial imagery is utilized by both the private and public sectors.

Consider the fact that high spatial resolution, multispectral imagery collected from space is clear enough to distinguish cars, painted lines on streets and highways, chalk lines on football fields, and can "see" damage to trees and crops not visible on the ground or to the naked eye, anywhere on the planet each day, and can be supplied to a desktop computer within hours after collection.

The earth imaging market is essentially leveraging off the $6 billion Geographic Information Systems industry which is growing at more than 14% annually. We estimate that the current imagery-related mapping market (aerial photography and satellite imagery products) may total around $2 billion annually, and with the introduction of new, high spatial resolution satellites could double within a decade.

Applications for the emerging commercial space remote sensing business include infrastructure planning and management (local, municipal and state government, utilities

and telecommunications, transportation); oil, gas, and mineral exploration, development, transportation and refining; forestry; agriculture and commodities forecasting; coastal zone monitoring and management; national security; as well as the environment.

EarthWatch has designed our satellites with the capability to serve a wide variety of environmental customers, from state and local regulators to global researchers. The satellites have the ability to monitor changes over both large and small areas, from thousands of square kilometers to a few square meters. On a micro scale, the high spatial resolution multispectral imagery can be used to monitor water pollution discharges, hazardous waste disposal and cleanup activities, forest fire damage assessment, illegal logging, and many others. On a macro scale, EarthWatch imagery can contribute information important to several areas of global change research:

- *Atmosphere* - cloud cover, volcanic activity
- *Oceans* - wetlands destruction, near shore bathymetry, coastal morphology
- *Land* - deforestation, urbanization, surface hydrology, digital elevation model s (to a few meters accuracy), and natural disasters such as hurricanes, floods, earthquakes, forest fires, and drought.

EarthWatch is a result of the merger of WorldView Imaging Corporation and the commercial remote sensing programs of Ball Aerospace & Technology Corporation. WorldView Imaging was the first company to obtain a license and begin development of low-cost, high resolution imaging satellites and related new data products for the commercial and public sectors. Ball Aerospace has long been a leader in remote sensing and other space technologies.

Our company brings together expertise in remote sensing technologies, Geographic Information Systems, satellite systems, space-based instruments and ground station engineering. Over the past two years, we have developed a business model involving strategic alliances and investments from international industry leaders. At present, these partnerships involve Hitachi, Ltd; Nuova Telespazio s.p.a.; CTA Space Systems, Inc.; MacDonald, Dettwilerr & Associates, Ltd.; and Datron Systems, Inc. In coming months, we will be announcing additional strategic partnerships, as well as distribution agreements with a diverse range of corporate entities both here and abroad.

We have designed the EarlyBird and QuickBird satellites to collect and deliver imagery data in the most economical manner using off-the-shelf technologies, but at the same time maintaining spectral continuity with existing satellite systems. With a true 8 bit pixel depth and in-track and side-to-side pointing, the EarlyBird offers in-track stereo capability and fast revisit times not seen until now in commercial sensors. It captures wavelengths in the green, red and near-infrared spectra, the same bands as France's SPOT satellite. QuickBird specializes in high resolution and large area coverage, utilizing an advanced scanning array sensor. It will capture wavelengths in the blue, green, red and near-infrared spectra, the same as four of the bands on the Landsat Thematic Mapper, offering an 11 bit pixel depth. The QuickBird's dynamic range enables it to retain image quality in low-contrast scenes and under low-light conditions.

What all this translates into is a system that gathers data for specific targets over large areas, with an unparalleled degree of positional accuracy (within a few meters for both horizontal and vertical). With the deployment of our first satellite this year, the marketplace will witness the first commercial space imaging supplier providing private and public sector users with timely, high resolution images covering any area, virtually on demand. Our ingredients for success include deployment of small, lightweight satellite technology, combined with efficient data management and on-line delivery processes to allow to generate cost-effective, high quality information for commercial and civil applications.

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Notwithstanding the fact that we are designing and building our own satellites, EarthWatch views itself as fundamentally in the information dissemination business. As a market-driven organization, we understand that our success or failure ultimately depends on our ability to deliver what the commercial or government end user needs -- in the format that best meets their needs, at an affordable cost, and in as timely and efficient manner. As a result, EarthWatch has dedicated itself to developing a unique network for acquiring and distributing its satellite imagery. Called Digital Globe™ it is a worldwide information database composed of a range of imagery and geographic information products, electronically delivered to the desktops of our customers.

Satellite imagery will be downloaded to EarthWatch ground stations in Alaska and Colorado. Regional EarthWatch ground stations in Europe and Asia will soon come on-line. Imagery data are sent from ground stations to the EarthWatch Master Archive in Colorado for processing, storage and delivery. Raw image data may be processed into system-corrected products, which are quality-controlled for accuracy and to eliminate atmospheric image obstructions. EarthWatch distributes images to customers via digital pathways, including the Internet, and all images will be incorporated into the EarthWatch Master Archive. This Master Archive serves as the backbone of our Digital Globe™ which is intended to offer a comprehensive model of the planet with images and topographical data of land surface. It will utilize images from EarthWatch satellites as well as imagery and information from other commercial resources.

The idea behind Digital Globe™ is that customer can use an on-line service to allow our customers to purchase the Earth by the pixel, allowing the end user to download just the information they need. It will include both historic and new imagery that will provide a foundation for the next generation of GIS, mapping and multimedia applications. In addition to the on-demand imagery delivery just described, various processed data products will be available, including:

- *Precision-Corrected* - seamless, geometrically corrected image data delivered in any required map projection. This type of image is ideal for use as a reference backdrop for many GIS applications.
- *Terrain-Corrected* - a higher order of image processing X, Y and Z data to correct distortions, including those caused by terrain relief.
- *Digital Terrain Models* (DTMs) - elevation data corresponding to individual image pixels.
- *Perspective Views* - realistic perspective views of the terrain, suitable for use in general purpose terrain visualizations.

At present, EarthWatch is primarily focused on addressing commercial and civil mapping needs, and does not for the moment have plans to incorporate government science requirements into our systems. On the other hand, if the government approached us with an interest in purchasing imagery data, EarthWatch would certainly be interested in exploring the issue further.

The current state of satellite technology enabling EarthWatch's business opportunity was developed over the last 30 years by the US government. Given this fact, it seems appropriate that the US government investigate possible cost savings to planned programs through working with our emerging industry.

From the standpoint of the government user, we believe that there are several benefits to using private data providers to meet certain requirements. Examples include:

- government capital is not at risk if the satellite fails. The government ,in effect, is leveraging private sector capital to meet public sector information needs.

- the government incurs no major operations cost or overhead costs since the private sector provides products as opposed to simply providing satellites;
- the data products can be provided at affordable prices since the development cost can be spread over a large customer base;
- the data products can be made available in bite-size chunks -- the customer can buy as much or as little as they want. This means that a government customer doesn't face the no-win decision in times of reduced funding of either canceling a program or else accepting a schedule slip. Instead, they have the option of simply buying less data.

As I stated earlier, at present no commercial market for scientific data exists, so it is not part of our current product offering. On the other hand, the incremental cost to EarthWatch of including a capability to collect data of scientific interest is probably not large. (Needless to say, this would be easier to accommodate if such a government commitment to buy from private data providers were to materialize prior to launch of our satellite.) One example may help make this point.

We currently perform ground-based calibration of our sensors -- relative (pixel-to-pixel) to roughly +/- 0.25% and absolute to about +/- 5%. We do relative calibration on-orbit to better than +/- 2% over the life of the satellite, but there is not a substantial commercial requirement for absolute calibration on-orbit, so we don't do it. Although we could use ground-based measurements after the launch to implement such an on-orbit calibration, it would be more cost-effective to do so (once a customer base for data materializes) by incorporating on-orbit absolute calibration in our future spacecraft.

As noted earlier, our business does not depend on substantial US government procurements. On the other hand, we believe that innovative strategies for structuring partnerships between the government and the commercial earth imaging sector offers major advantages to both sectors in this fiscally constrained climate. In that regard, Mr. Chairman, we applaud the language in the current draft of your "Omnibus Space Commercialization Act" that calls on NASA to buy remote sensing data and services from the U.S. private sector, as well as undertake a study to determine the extent to which the scientific requirements of Mission to Planet Earth can be met by the private sector.

If there is sufficient interest by the government, we would be pleased to explore win-win arrangements. One possibility might involve NASA as a buyer of data and services ,and in turn, industry would incorporate the necessary technologies to accommodate those requirements. The agency would have their needs met at potentially significant budget savings; with the private sector using this expanded customer base to create new markets and jobs. In addition, commercial remote sensing imagery will be available, and distribution systems operational, years before EOS and EOSDIS, potentially laying the groundwork for an global database, which in turn, could contribute to effective, near-term, environmental decisionmaking .

The rapid evolution of our industry since this Committee took the lead in securing passage of the 1992 Land Remote Sensing Policy Act suggests that this hearing comes at a time of extraordinary promise for commercial space imaging. On the regulatory and policy fronts, the government has promoted U.S. private sector leadership in satellite remote sensing. We look forward to working with the federal government to explore how we might work together as partners to ensure long term U.S. leadership in using space-based systems to most effectively meet the requirements of both the private and public sectors, especially in the areas of global change and environmental monitoring.

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BIOGRAPHY

Dr. Eric Christensen has over 14 years experience in the remote sensing and environmental industry. Prior to becoming Director of Government Marketing at EarthWatch, he spent 5 years at Lockheed helping start their commercial remote sensing business as Manager of Market Research. Dr. Christensen received his Ph.D in remote sensing from the University of South Carolina (USC), and has Master's degrees in Business from Cornell University and Chemical Oceanography from USC, as well as Bachelor's in Chemistry and Biological Science from the University of Delaware.

Chairman WALKER. We'll go to questions now based upon when members came into the room.

Let me lead off.

Dr. Frieman, first of all, I wanted to thank you. I appreciate the fact that you indicated that some of the questions that we've been raising along the way are in fact legitimate questions based upon the findings of your group and that this is not an adversarial nature. They're just legitimate questions that arise out of the nature of the program that we're talking about.

One thing that you did not cover in your testimony today that you mentioned in a briefing that you did for us back when the study was completed was that your concern about the fact that some of the ground stations within the data collection system appear to have been selected more with politics in mind than with good management in mind in terms of science data collection.

Would you elaborate on that a little bit?

Dr. FRIEMAN. Well, Mr. Chairman, that was I guess what was in the rumor mill in those days.

Since then, of course, the structure that has been recommended in terms of the way that EOSDIS might go forward would envision a completely different structure.

So we haven't really gone back and examined that issue since then at all. We're waiting for NASA to come forward in response to a restructured EOS data and information system. And I guess my assumption had been implicitly that that issue would then just disappear from the table.

So that's the best I can say at the moment.

Chairman WALKER. Do you, based upon your study, agree with the point, and I don't want to misrepresent Mr. Hathaway's point, but I want to try to pull together some of the things that I've heard here today.

I think one of Mr. Hathaway's points is the fact that there is some concern when the GAO looks at the funding profile of whether or not there are going to be enough investigators downstream to actually utilize all the data that is going to be generated.

Do you agree that that's a great concern?

Dr. FRIEMAN. It's certainly an issue which we have discussed. Clearly, as budgets ramp down, it becomes more and more difficult.

I can only say that, from the point of view of the scientists, the graduate students who are facile at getting into Internet—for example, we have something up on the Net, it's called a Data Zoo. And we get thousands and thousands of hits.

So it's not completely clear to me that there's sort of a one-to-one correspondence that everybody needs to be supported under this program in order to use the data. My assumption had been that once that data is available, it will be used world-wide on some very large basis.

Chairman WALKER. Well, Mr. Hathaway, but if I remember some of the points that are being made by the GAO, we're not even certain that we have enough people designed within this funding profile to do appropriate archiving of all the information that's coming down.

Mr. HATHAWAY. The archiving side is not part of the comparison that I was presenting to you. We were trying to focus more on the

basic research once the material is available, as opposed to the EOSDIS side of the coin.

The point that I wanted to make there was the point that I had made in the statement about the scientists analyzing the data that they are paid to analyze. I'm aware of your Internet site.

As a matter of fact, I'm one of those that clicked on a couple of times and got counted in that, and I doubt very much if auditing is the kind of activity that they were looking for when they set that up.

So there are many users in the EOS user community. There was a conference last year attempting to identify that user community. It divided them into 12 groups in order to attempt to look at how well they were being served.

Only three of those groups, however, were primarily composed of scientists. They got into the educational side. They got into the commercial side. They got into travel.

A lot of that.

Chairman WALKER. Sure. But the concern here is that if you look downstream, if you take the information that we already are prepared to develop through the AM-1 satellite, through Landsat, to all of the things that Dr. Kennel indicates are going to come on line in 1998, and then if you take what's also available potentially from the commercial community, my question is do we have enough investigators built into the budget to even handle what we are going to bring down and have available to us in 1998 and for the next two years out to 2000?

Is there sufficient provision for that within NASA's budget at the present time?

Mr. HATHAWAY. Well, we're waiting to see the release of the '97 budget.

Chairman WALKER. All right. Well, but let's take—because we don't have that, let's take the '96 budget as a guideline. Is there enough money when you look out to the year 2000, to fund the kind of investigators that would be needed for just the amount of data that we already know is available?

Mr. HATHAWAY. To catalogue and operate on——

Chairman WALKER. Yes, because if you can't catalogue it, it can't be used on the Internet, for example.

Mr. HATHAWAY. That's right.

Chairman WALKER. If you're going to put this out to a wider community through the Internet, you've got to have at least enough people to catalogue the information.

Mr. HATHAWAY. With the restructuring proposals that have been put out, I think I'd probably yield to the Doctor for an opinion on that.

Dr. FRIEMAN. Mr. Chairman, I couldn't say at this point that with the conceptual structure that we gave to NASA at the end of last summer, how those numbers are going to work out.

I think it's clear that there's one issue here, which is that the kind of data that's available will be sitting there for years and generations of people will reach into it.

It's just not a one-to-one kind of thing.

Chairman WALKER. Precisely. But providing we have sufficient people to archive the information.

Dr. FRIEMAN. You need to provide the adequate source of resources to do the archiving.

My assumption is that under the EOSDIS budgets that previously existed, that was part of those numbers. I can't guarantee that, but our assumption was that under the new structure, that kind of federation that we've been talking about, even if the EOSDIS numbers came down, that that archiving function will continue. And we even specified where the archiving needed to be done.

Chairman WALKER. Okay. Well, I want to get to some of our other colleagues, but I do need to go to Dr. Kennel for just a moment.

First of all, on this question, Dr. Kennel. Are you confident that we have enough investigators to use the information stream that's available right now, beginning in 1998, with AM-1, Landsat, to both do the investigations that are current and then also to do appropriate archiving?

Dr. KENNEL. Yes. But I'd like to make two rather general points.

The first, when I grew up, I listened to the radio and I got 2000 or 10,000 bits per second. Now I watch the television, with hundreds of times more information.

We are a society that is beginning to develop the capabilities of using large amounts of information.

Chairman WALKER. Sure.

Dr. KENNEL. And so I think the actual volume of information is not the issue. The real issue is of course what science we can do with it now and what science we can do with it in the future.

So I'd just like to say that the volume—our capability for handling the information will be so great and we want to be a leader in stimulating the ability to deal with it.

Chairman WALKER. But that means, but in order to do that, it means purchasing the technology that's capable of handling those new volumes of information.

Dr. KENNEL. Yes.

Chairman WALKER. Is the budget sufficient to handle all of that new technology?

Dr. KENNEL. Yes. The bringing down and archiving of the data is, I believe, two-tenths of a percent of the budget. A good deal of it is spent on the production of high-order data.

But there will certainly be the capability of investing and correcting all of that data.

Chairman WALKER. You indicated that what you were going to have was a science-driven program, and I think that that's absolutely essential and I'm delighted to hear that.

There has been some concern expressed to this Committee that NASA-funded scientists who are not coming up with data sets that fit kind of the current orthodoxy are going to be among those who are going to be defunded.

Can you give me an assurance that that will not happen?

Dr. KENNEL. I guess I don't know the particular concerns that have come to you.

Chairman WALKER. Well, there are some people, for instance, who have data sets that don't fit with where kind of the general community is going.

You all have been funding them and they are in fact producing some science that is not exactly in line with others. What I want to make certain is that some of the people who are saying some things different from the general are not in danger of being defunded simply because they appear to be out of the mainstream at the moment.

Dr. KENNEL. I think that's highly unlikely. I would like to—I think the point to be made, the new federation approach, which we will respond to, will allow a wide variety of data sets produced by Mission to Planet Earth, not produced by Mission to Planet Earth, to be interlinked with a common protocol.

And it's this flexibility, I think, that is so interesting to us. We intend to fund all the data that is available.

Chairman WALKER. You said that you were going to utilize some commercial data sets.

Dr. KENNEL. Yes, sir.

Chairman WALKER. Who are you talking to on that?

Dr. KENNEL. Well, we have sampled a number of the commercial entities that are currently building——

Chairman WALKER. Dr. Christensen, have they talked to you?

Dr. CHRISTENSEN. Unofficially, we've had some contact, but officially, no.

Dr. KENNEL. But he pointed out the central issue for us, where we need to work with industry to improve the situation. And the issue is on the area of calibration.

Chairman WALKER. Okay. That's very helpful. Let me begin with some of my colleagues now.

Mr. Volkmer?

Mr. VOLKMER. Thank you very much. So we can get maybe the basics in this, Dr. Frieman, I'd like to ask you to think just for a little bit, and I'm not going to ask you a question now. I want you to think about it, and then I'll come back to you.

What is the data that we want our scientists to have from the Earth Observing System? What type of data.

Do you understand? Okay. Think about it.

Now, Mr. Hathaway, you have—basically, your testimony leads me to believe that the problem we're having with the EOS systems is the fact that we're going to run out of money down the road and not really going to be able to do it.

Is that right?

Mr. HATHAWAY. No. The task facing NASA is to come up with a structure within the budget's constraints that gets the most data and the most science out of that.

My concern was the balance between the elements, not necessarily the bottom line. The bottom line is something that they're struggling with even as we speak.

Mr. VOLKMER. All right. But you're not saying, then, that the budgetary figures, as we look out to the year 2000, is going to cause us trouble?

Mr. HATHAWAY. We already look even beyond the year 2000. When you talk about the life cycle costs of the program, we've reported a $33 billion life cycle program which clearly is not affordable.

NASA is aware of that. NASA has been working on that. NASA is bringing that down.

Mr. VOLKMER. I understand that. So you are saying that the budgetary constraints are a problem.

Mr. HATHAWAY. The budget picture over the next ten years or the next 20 years, or whatever figure you want to pull, they have a real challenge in front of them, yes, sir.

Mr. VOLKMER. In order to do everything they want to do within the system.

Mr. HATHAWAY. Yes, sir.

Mr. VOLKMER. Totally. All right. Now, if I started cutting back in funding on that by $100 or $200 million a year, are they going to have more or less trouble?

Mr. HATHAWAY. They are going to have more trouble doing the same amount. Therefore, they've got to make their priorities and they've got to decide what not to do and you've got to decide what not to do.

You're absolutely right, sir.

Mr. VOLKMER. All right. In other words, it will be detrimental to the program to reduce it by any more amount than what it is now.

Mr. HATHAWAY. There will be less value bought for less money, sir, yes, sir.

Mr. VOLKMER. All right. Now Dr. Frieman, would you give me the answer?

Dr. FRIEMAN. You asked about data sets and the collection.

There is a very structured response to that, and I can answer it in two ways.

Number one, I pointed out that there are four major science areas which need to be investigated.

Mr. VOLKMER. I understand that.

Dr. FRIEMAN. And that there are a class of 24, I believe, is it, Charlie?

Dr. KENNEL. That's right.

Dr. FRIEMAN. 24 specific data collection issues, items, if you will, which map into those four.

Mr. VOLKMER. Fine.

Dr. FRIEMAN. And so that is the current structure of the program. Those things are very well integrated. They're very well linked. I think many members of the scientific community have contributed to that. But that is the current structure.

Mr. VOLKMER. Right. And that dictates the type of instrument and the type of platform that you use.

Is that correct or incorrect?

Dr. FRIEMAN. Are you addressing that to me or him?

Mr. VOLKMER. That's to you first.

Dr. FRIEMAN. It dictates it within the kinds of constraints that Aram Mika talked about.

That is, you have a certain set of instruments. They have a certain size. They have a certain set of data rates and you put them on and fly them the best you can and the cheapest you can.

Mr. VOLKMER. Mr. Mika, is that correct?

Mr. MIKA. Yes, sir.

Mr. VOLKMER. Now Mr. Christensten, what do you have to say about that?

Dr. CHRISTENSEN. Can you be a little more specific in terms of how you want me to answer the question?

Mr. VOLKMER. Well, basically what I'm hearing from them is that the instruments that are being proposed be flown on the platforms that are to be used at least for the AM-1, PM-1, TRMM, Landsat 7, et cetera, are dictated basically by the need by the scientific community what I call knowledge, data base, the type that they want to come back.

And Mr. Mika says that the instruments that they are proposing to construct to provide that data is based on that need.

Dr. CHRISTENSEN. Right.

Mr. VOLKMER. Now I want to know from you because when I read your testimony, it appears to me that you're saying, I can do that differently, at a lot less cost, a lot easier, that very same thing.

Is that what you're telling me?

Dr. CHRISTENSEN. No.

Mr. VOLKMER. Thank you.

Dr. CHRISTENSEN. What I'm saying is that, essentially, NASA has the opportunity to work with the private sector to see what the answer to that question really is.

I don't know if it's yes or no.

Mr. VOLKMER. All right.

Dr. CHRISTENSEN. But nobody has come and looked at the technology that we have to bring to the table that perhaps could answer the question yes.

Mr. VOLKMER. Well, Mr. Mika, are you a federal employee or are you with the private sector?

Dr. CHRISTENSEN. I'm with the private sector.

Mr. VOLKMER. I'm talking about Mr. Mika.

Mr. MIKA. I'm with the private sector.

Mr. VOLKMER. That's what I thought. So we have the private sector.

Now, I'm not saying you shouldn't be, Dr. Christensen. I think that perhaps—and someone correct me if I'm wrong about this—as we get past the first four satellites and we get into the smaller or intermediate types, then I'm sure that what Dr. Christensen is bringing to this table today is very important.

Am I correct in that or incorrect in that?

Dr. FRIEMAN. Yes, sir. I think, if I might expand a little bit on my previous answer.

Mr. VOLKMER. Yes.

Dr. FRIEMAN. There's a presumption that EOS maps the answers to the four science questions, and that is just not so. There's much more that needs to be added in terms of ground sensors, in situ sensors that have been mentioned. There's much more that has to be added by other agencies. The list goes on and on.

So there's room for all of this, as we try to encompass the total picture of what the Global Change Research Program is going to do. EOS is a large part of it, but it's not the whole thing.

Mr. VOLKMER. Thank you very much, Dr. Frieman.

Chairman WALKER. The time of the gentleman has expired.

The vote is on the journal. We will recess momentarily and go vote and come back right after that.

[Recess.]

Chairman WALKER. Ladies and gentlemen, we want to reconvene here. We want to try to keep things on schedule.

Have we lost some of our witnesses? We get a vote on the journal and we lose members and witnesses and everything else.

[Laughter.]

All right. Let me turn to Mr. Cramer, since he was good enough to get back here in a timely fashion, and let him ask some questions.

Mr. CRAMER. Thank you, Mr. Chairman. That's a nice reward for a journal vote.

[Laughter.]

Chairman WALKER. I know about those.

[Laughter.]

Mr. CRAMER. It's certainly an interesting hearing here today and I'm looking forward to the next panel as well.

I want to try to focus some questions here.

It seems that Mr. Hathaway has pointed out that we need to carefully think through how the basic science will get done for EOS, and this is a definitely a good idea. And on the next panel, we will hear from Dr. John Christy from the University of Alabama in Huntsville, who made a major contribution to our understanding of the climate and has strengthened the scientific basis for EOS.

I want to address getting ready for that testimony and some of the questions that the Chairman asked and some others were getting into. I want to address this to Dr. Kennel, if I'm saying your name right.

Dr. KENNEL. Yes, you are.

Mr. CRAMER. In your planning, how can we continue to stimulate this kind of science?

And let me help you with that. I don't think the answer is to cut funds, but I think we need to look at how we leverage our resources.

I'm concerned to some extent about NASA's approach toward its science, Marshall's role in that science, the wonderful resources like Dr. Christy, that I don't want him to have to move to Goddard in order to keep doing the kind of work that he and they have been doing.

So let me ask you how you see that fitting in.

Dr. KENNEL. I can understand your concern.

With particular regard to Marshall, I was very pleased to play some role in the development of the Global Hydrology and Climate Center, which is a very innovative partnership between NASA and the University of Alabama system and I guess the USRA and several other groups.

Here, the idea was that we could take a significant capability within the government and partner it with a significant and complementary capability within the university community, including USRA, and produce a whole that was greater than the sum of its parts.

And so we hope that the intellectual and scientific interchanges that take place between this significantly broader group will broaden NASA's program, will strengthen the university. And I think we

would like as much as possible, wherever these things work, to seek partnerships like that in the future.

Mr. CRAMER. All right. And now, a question for the GAO.

In your testimony, you seem to imply that EOS alone is responsible for the NASA budget being out of sync with OMB guidelines.

How do you reach that conclusion?

Mr. HATHAWAY. No, sir. I'm sorry. I didn't mean to give you that conclusion.

The NASA budget that we talked about at $33 billion as a life cycle estimate for the EOS part was only one piece of the gap that we reported in 1992, that NASA's budget projections did not support NASA's program projections.

That is the point at which in 1992, when we pointed that out, that restructuring and—you have the numbers of R's: rebaselining, reprogramming, restructuring, rephasing, in order to bring NASA's budget back into a role where it was, their projections for budget matched their projections for programs.

That was a NASA-wide effort, not just an either MPTE budget or an EOS budget exercise.

That gap closed. By 1995, they were very close to closing that gap.

The 1996 budget, however, with reduced projections for outlays in the balance of the century, it began to reopen again. Now, at the same time that they were doing all of that restructuring for all of the programs, or at least many of the programs within NASA, they were also doing so in your office and they continue to do that.

And for that matter, in many of the other government agencies throughout the government.

It was not just EOS and it certainly was not just Mission to Planet Earth. It also wasn't only focused on the archiving or distribution or analysis of data.

I think in our conversation before the break, there was a co-mingling of the issues of archiving and distribution and basic research.

The point that I had been making earlier about the number of science teams was the conduct of basic research, not the archiving, not the distribution, not the creation of the data sets.

It is in that area where, I understand you can archive the data and study later and all of that, but you're still going to be in a situation where scientists do scientific research that they're paid to do and we, in looking at NASA's process, noticed that they intend to try to expand that community through savings. I don't know where those savings are coming from. They may not be able to get there with that.

Mr. CRAMER. Fine. Thank you for that clarification. And then I want to make a point here. I should know this, but I don't.

Where are we with the National Academy of Sciences study? Have we finished that?

Mr. HATHAWAY. Well, Dr. Frieman, you want to elaborate on what happened after the July conference?

Dr. FRIEMAN. The situation, I believe, is as follows, Mr. Cramer. We reported in, reported to the chairman. At that time the report was issued. All of the federal agencies that are involved in the Global Change Research Program, Executive Office of the President, people up on the Hill have been, I think, working very hard,

very industriously to respond to the questions that the Chairman first raised and there have been the recommendations that followed.

As I think I said earlier, the report back, the detailed report back is actually occurring today, tomorrow, these next three days.

So where we stand at the moment is on the basis of informal discussions and so on and so forth. But we have not yet heard the bottom-line response.

Mr. CRAMER. All right. And Mr. Chairman, if I could just make a comment on behalf of my role in this Committee.

I hope we can defer further action on this program until we do have that study finished and until NASA can respond to that. I don't know what your intentions are, but I hope we can await that.

Thank you.

Chairman WALKER. Thank you, Mr. Cramer.

Mr. Salmon?

Mr. SALMON. Thank you, Mr. Chairman.

I've had a rather positive experience. I represent part of the City of Scottsdale in Arizona. We've had a real positive experience with one of the programs, or a pilot program, through the Mission to Planet Earth program. And I know that it can provide not only data for the science community, but essential, long-term, global change information to state and local governments which are increasingly concerned about the long-term economic viability and environmental stability.

The program can be the premier linkage between local government, community planning, and global issues which will likely impact our cities for centuries.

I give you my compliments for the assistance and the pilot program within the City of Scottsdale.

However, with our times of fiscal uncertainty and austerity, every government agency is asked to do more with less. And it's encumbent on this Committee to ensure that all of our space programs are cost effective and designed to meet their goals.

Today's hearing has given us, I think, a great opportunity to juxtapose those conflicting goals of trying to—well, not necessarily conflicting—but the goals of good science and also of making sure that we do it in the most cost-effective manner.

I do have a couple of questions.

Dr. Frieman, the study team that you assembled to review Mission to Planet Earth last year, how many of those members were voting members of the National Academy of Sciences?

Do you know?

Dr. FRIEMAN. I don't know offhand. Just thinking about faces around the table, one of my colleagues is sitting right here, who is a member of my section of the academy. There were others.

I don't know how many, though.

Mr. SALMON. I hope my information is accurate. I just wanted to test that and see if it was accurate.

According to the information I have, only four members of the committee were National Academy of Sciences members, including yourself.

I do have one other question of you. Were any of the members of the study team participating in any aspect of the Mission to Planet Earth?

Dr. FRIEMAN. Many of them were. I would suspect that of the experts we assembled, I would say that a very large fraction of the people were supported by one government agency after another. We declared that up front in the study.

Mr. SALMON. I understand.

Dr. FRIEMAN. To go on record on that point. So I think you will find in the preamble to the report that that issue is raised. We understand the sensitivity, but, in fact, the report went through the standard very careful scrutiny of the National Academy Committees over and above ours before it was ever released, looking for precisely all of the sensitivities and the report that emerged came from that point.

Mr. SALMON. I know that, having been a former state legislator myself, and also one that worked in the private sector at the same time I was a state legislator, I was an executive in the telecommunications industry. And the press and the public looked at me very, very carefully whenever telecommunications issues came up to make sure that I did not inject a conflict of interest.

So I'm real sensitive to those issues that many times as policymakers, we have to be very, very careful of the public perception of studying or issuing reports when you have a vested interest in the outcome.

At least that's the perception. I'm not saying that's the reality with you. But that's a concern.

Dr. FRIEMAN. It's clearly a concern. I think, as I mentioned in my earlier remarks, we felt we were balanced because we criticized everybody, including the agencies that support the people on the committee.

Mr. SALMON. Okay. Thank you. I'm going to move on to Dr. Kennel.

Dr. Kennel, by the way, let me tell you that I believe that your boss, Mr. Goldin, is probably one of the most top- notch—probably the most top-notch administrator I've met in the Clinton Administration.

Dr. KENNEL. I agree with you.

[Laughter.]

Mr. SALMON. I think he has really done a yeoman's—I mean that. I really do.

Chairman WALKER. We'll note that for the record.

[Laughter.]

Mr. SALMON. And I'll tell him you said that. But I think that he has really done a yeoman's job. He's brought a lot of private-sector expertise to this position, which I think has really helped him in trying to do more with less. He really understands what it's like out there in the real world, and I appreciate that.

In your prepared statement, you suggest that your study was cognizant of the budget constraints that Mission to Planet Earth faces and its recommendations would provide taxpayers with savings in the program.

Yet, NASA has told Congress it does not plan to change the Mission to Planet Earth budget through the year 2000.

I'm having a little bit of trouble reconciling those two testimonies. NASA says they can't cut the MTPE program over the next five years. The National Research Council endorsed their approach.

Yet, I gather from your statement that the NRC's recommendations would save money. Can you help me with that?

Dr. KENNEL. Yes. Let me also indicate that we're just building this program. We're trying to get it off the ground. It was founded in 1991 and we started building the program and we had aimed basically for a 1998 start and a full operation in the year 2000.

So it has a natural ramp-up that is associated with building the program. A decision was taken years ago to start that.

What has happened is that through the rebaselinings and the reshapings and all the REs that you mentioned, we have changed the perception of the cost in the future and our expectations and we brought that future growth more and more into line.

That is basically what has happened.

Now, in 1994, we ran an exercise called rebaselining, in which we were asked to take three-quarters of a billion dollars out of the up-front part of the program. We did that. And at the end of that time, we arrived at a perception which can always be probed. We arrived at a perception that if you want to continue doing the science that has been laid out by the various committees on this program, and if you want to do it in the time scale available, then we were fairly close to being in the box on the optimum costs.

There are always things that you can do, but large cuts would then produce large cuts in science.

In 1995, then, we asked the following question, that the continuously growing profile of the program through the year 2010, as the GAO correctly recognized, was unsustainable, was inconsistent with any budget profile.

And so the second question that we asked was, then, how do we make this program closer to sustainable over the long-term? And there we understood that we could accelerate the rate in which we infuse new and faster and better and cheaper technology into the implementation of the program.

We have done that.

In addition, we scrubbed the front end of the program in various ways, looking at EOSDIS, and we took some of that money and we have invested it in those programs, particularly New Millennium, which will enable us to achieve those cost savings in the future.

In other words, the investment in the re-engineering and the downsizing of the instruments is the critical thing.

And so, it is from that point of view, then, that we repostured the program so as to be more cost-aware.

The other thing that we did, and I'd like to repeat this because I've said it two or three times, we intend to look at this program every second year and capture every technical innovation we can and every partnership that we can, and by posturing us in this way, we hope to encourage the partnership so that ones that don't exist today will be more possible in the future and may become more real and may be a cost offset.

Mr. SALMON. Okay.

Chairman WALKER. The time of the gentleman has expired.

Mr. SALMON. If I could just make one follow-up statement, Mr. Chairman.

I know that one of the concerns that we have is that we are faced with budget realities now long before the year 2000. It seems that you're talking about savings post-2000.

You've heard the phrase, all dressed up with no place to go. Mr. Walker made the comment, I think the observation, a while back that one of the concerns is all this investment in capital, yet, will it be possible that we won't have an adequate number of scientists even to interpret the data once we've invested all this money in hardware?

Those are some of the concerns I think that this panel has. Thank you, Mr. Chairman.

Dr. KENNEL. Yes, I understand.

Chairman WALKER. Mr. Roemer?

Mr. ROEMER. Thank you, Mr. Chairman.

I'd like to continue with Dr. Kennel. Dr. Kennel, Dr. Christensen stated that funding data purchases from a company like his could fill MTPE data needs in the interim before EOS comes on line.

In your opinion, is that really realistic? Wouldn't that just draw funding from the EOS budget and then delay that program even further?

Dr. KENNEL. Well, let me—I think each of us has a different interest.

In the commercial area, they're interested in looking at, as he cogently mentioned, high-resolution data, one meter. They're interested in that. And many of the applications that they foresee are in this area.

In Mission to Planet Earth, where you're dealing with global problems, you're interested in global coverage. You're interested in instruments with less fine spatial resolution and broader coverage.

And so, there is only a partial overlap of interest between the scientific goals of Mission to Planet Earth and those of the commercial community. And it is in this interface area between low-resolution, broad coverage instruments and measurements on the Mission to Planet Earth side and high-resolution. And it's in this interface area that we foresee in the future a good technical partnership, provided that we can work out with the industry enough capability on all sides so that they can meet our scientific needs, which will include certain standards of continuity, especially calibration coverage and timeliness.

And so, the work needs yet to be done to forge such a partnership.

Many of the scientific objections in Mission to Planet Earth have no apparent application at the present time. That's the other aspect of things.

Mr. ROEMER. I may want to submit some questions in writing to follow up on your answer.

Dr. KENNEL. We would be very happy to comply.

Mr. ROEMER. In times of tightly constrained budgets and work force downsizing, I'm concerned that we do nothing that further impedes your ability to carry out the ambitious and challenging Mission to Planet Earth program.

What would be the impact on your program of the proposed provision that would not allow NASA to obligate any funds to procure Mission to Planet Earth systems unless NASA thereby certifies that no private-sector entity could provide suitable data in a timely manner?

Dr. KENNEL. This has the possibility of being quite a complexifying step.

Mr. ROEMER. Could you elucidate on what complexifying means? [Laughter.]

Dr. KENNEL. It would make our life more complicated. We're trying to do faster, better, cheaper. And one of the aspects of it is to make fast decisions.

We're trying every second year to implement and complete review and insight, try to gain full insight of what the capabilities are of the commercial community. Every second year, Congress will have full insight into that. And we think if we had to go through a contentious process in which all sorts of folks came into the arena and made claims that they could make individual—it would make the whole decision process very complicated and we're afraid that it would defeat our overall goal of trying to be more agile.

Mr. ROEMER. So some of the success that Dr. Goldin talks about in terms of, Administrator Goldin talks about in terms of faster, cheaper, better, in terms of some of the successes that we've seen in recent, in this past year, with Galileo and other programs, would that jeopardize any of those other programs, as well as what you might do in these areas?

Dr. KENNEL. Well, I think if a technique like this were proposed in broader areas, it would presumably have the same effect.

Let me just say that Mr. Goldin, I think, is very fond, probably has mentioned to you, the faster, better, cheaper includes the Congress.

If we're going to make agile decisions, we need your help. And we're willing to work with you in ways that we can make those decisions, and this may be one, this may be a way of certifying commercial presence that is not necessary.

We think we could probably earn your confidence.

Mr. ROEMER. I understand cheaper and better for Congress. What does faster mean for Congress?

[Laughter.]

Dr. KENNEL. That's your part. We'll try to do our part of the job here.

Mr. ROEMER. All right. Thank you, Mr. Chairman.

Chairman WALKER. Ms. Cubin?

Ms. CUBIN. I have no questions at this time, Mr. Chairman.

Chairman WALKER. Thank you. Mr. Weldon, any questions?

Mr. WELDON. [Florida] I thank the Chairman. I have a question for—I got here a little late—Dr. Kennel.

NASA has informed Congress that it wants to start the Earth Systems Science Pathfinder program of small satellites to introduce some flexibility and ability to address our science requirements on the basis of changing science.

Why wasn't EOS initially designed with this flexibility in mind? If the EOS baseline program is supposed to acquire the needed

data in NASA's 24 data sets, then what added value does Pathfinder bring to Mission to Planet Earth?

Dr. KENNEL. I think one point I would make is that EOS is a program of significant duration. It's a significant commitment. And it has strong standards of continuity, calibration, coverage and timeliness.

And so, to commit to an EOS-level scientific investigation is in itself a significant thing.

Now, I reach the conclusion that at any budget level, the Mission to Planet Earth Program had to be in the posture of encouraging new scientific ideas. It is not right for a program to be so postured that however cogent the plans in 1992 had been, it's not right for those plans to constrain the development of science, including the opportunities to fly in space, in the year 2005.

And so we designed the Earth System Science Pathfinder program with a minimum amount of funding in the early years simply to encourage the development of new science that we are not doing well now.

We do not plan to continue these observations for 15 years. We might do it for two years, try it out. If it's pretty good, then they can argue to try to get into a flexible and evolving EOS later.

But I think it's wrong—at any level of the budget, you do need to provide opportunity for new ideas and the evolution of growth, new people, young people, expand the community.

And we're giving them a very challenging job because we're asking them to try to do all of this, their whole project in less than $120 million for everything.

Mr. WELDON. [Florida] I thank the Chairman.

Chairman WALKER. Mr. Tiahrt?

Mr. TIAHRT. Thank you, Mr. Chairman.

I've been reading through some of the literature and Dr. Ledebuhr, I believe in some of the information that I looked at, in '91, you talked about proposing the use of miniature spacecraft technology that was developed during the cold war to try to reduce some of the cost of the observation.

Has this been taken into consideration in your latest proposal here? Are you trying to capture what's already out there in the commercial environment?

It seems like you're developing at a great deal of expense a hardware that could possibly be redundant in what's available out there.

Could you respond to that?

Dr. LEDEBUHR. Basically, that proposal was submitted in '91, as an approach to the single satellite EOS concept at the time. We proposed, by going to a small constellation of small satellites with miniaturized instruments, that you could effectively get the same science yield, basically faster, cheaper, better.

That approach was basically not pursued. We instead built the support of the Clementine mission, which sort of demonstrated that a small sat with a payload of a half dozen instruments could effectively map an entire planetary body, multiple spectral bands and do it for under $100 million very quickly, in two years, in a two-year program effort.

We felt that the kind of technologies that the cold war had been pushing toward, allowed—was forcing us, to miniaturize hardware. Prior science payloads had large platforms to put their instruments on and there had not been the pressure, the technological pressure, to miniaturize things.

We felt that you could use that commercial drive in miniaturizing and upping performance to take advantage of that. Basically, what you saw from Dr. Christensen's high-resolution imaging systems, which are a fairly small satellite with advanced sensors.

I believe that it's possible to—we looked at the sensor designs of EOS in '91 and it showed how we felt, to our satisfaction, they could be miniaturized and put on small sats.

So we felt that that would actually not, would cost less and we felt, with the Clementine example, that it actually can be done.

Mr. TIAHRT. So are you saying that you're trying to incorporate this miniaturization in with the new configurations that you're proposing?

Dr. LEDEBUHR. Basically, we're off on the Clementine II, looking at building impactor probes to target an asteroid for high-impact experiments and mission sensors using this.

But we are not really pursuing or supporting in any way currently the Mission to Planet Earth program.

Mr. TIAHRT. For the type of data that you're trying to acquire, is there commercially available hardware in space now or hardware that could be modified?

One of the pushes we have in trying to control costs is going to what we call off-the-shelf hardware. I'm sure you're familiar with the term.

Is there that type of hardware out there that could be slightly modified at a lesser expense than what we're pursuing under your current proposal?

Dr. LEDEBUHR. I believe there is. I believe that many of the satellite bus technologies that are currently available, that are going into the commercial imaging ventures can be directly applied for the technology used for the spacecraft platforms.

In the sensors, there's many subsystem technologies that are compatible. All that's necessary is a focused effort where the goal is to minimize mass and at the same time maintain quality in the instrument design, maintain a calibratable instrument, and that's all do-able within the current state-of-the-art and I believe it can be done fairly quickly.

And our contention was that if we had started in '91, we could actually right now have ten satellites in orbit beginning to take this global data to build up the trends so that we don't have to wait another half-decade before we find out whether there are global warming effects.

Mr. TIAHRT. I guess you're with DOE. Is NASA following up on this type of approach?

Dr. Kennel?

Dr. KENNEL. Can I comment on that? I wasn't around in 1991, but I think that NASA's issues at that time were the doubts about the readiness of the technology to commit to making these measurements, were concerns about the calibration and there were is-

sues of whether or not we could get calibrated measurements through formation flying.

Having said that, let me just say that the presentation of the Brilliant Eyes, the demonstration of Clementine and various other discussions like that have had their effect on NASA.

And we are now planning, particularly in this second round—I think we share Dr. Mika's point of view that the present instruments that we are building, for example, are state-of-the-art and the best that industry can do, given the scientific requirements that we have.

But at the same time, we are going to invest in the development of the new and re-engineered instruments that are indeed smaller so that we can try to go in part towards the Brilliant Eye conception of multi-constellations of the spacecraft.

We are also, the program willing, in 1998, we are planning to try some formation flying exercises. We're going to fly Landsat and AM-1 in formation. It may even be able to pull Lewis & Clark in there. And if we have a Landsat demonstrator for a new instrument in that time period, we will definitely fly in formation.

So these ideas have had their impact on us.

Chairman WALKER. Thank you. Mr. Olver?

Mr. OLVER. Am I last, Mr. Chairman?

Chairman WALKER. Well, we're ready to dismiss this panel after the gentleman has asked his questions.

Mr. VOLKMER. I have some questions, Mr. Chairman.

Chairman WALKER. Mr. Volkmer?

Mr. VOLKMER. I'd just like to announce that I will have some questions that I want to address to Dr. Frieman and to Dr. Ledebuhr. And then as a result of those answers, I'll probably address some questions to Mr. Mika and Dr. Kennel.

So it may take a while to do that, but we'll do it that way.

Chairman WALKER. Gentlemen, thank you for your testimony. Let me invite the second panel, please, to join us at the table.

I would say to our panel as they gather at the table that I am going to use the Chairman's prerogative to be very firm on time constraints this time, and would ask you to do not only a Reader's Digest version, but specifically make that Reader's Digest version five minutes.

You will get a gavel from me after a five-minute presentation. So please summarize and then we will try to expand on your various point of views as we get to the questioning period with the members.

I'm going to begin today's panel with Dr. Watson. Welcome.

STATEMENT OF DR. ROBERT T. WATSON, ASSOCIATE DIRECTOR FOR ENVIRONMENT, OFFICE OF SCIENCE AND TECHNOLOGY POLICY, WASHINGTON, DC.

Dr. WATSON. Mr. Chairman, members of the Committee, I greatly appreciate being given the opportunity to discuss the issue of global climate change with you today.

The Administration, like most of the scientific community, believes that this is an extremely important environmental issue of profound importance to this and future generations.

My testimony is based on the latest scientific findings of the IPCC assessment, which was prepared and peer-reviewed by over a thousand scientists from developed and developing countries.

The IPCC conclusions represent the central view in the climate debate, a natural, not a forged consensus of the scientific community.

Many of the arguments you will hear today were taken into consideration by the IPCC.

While a number of key scientific uncertainties remain, hence the need for further research and monitoring, the majority of scientific experts believe that human activities have already affected the Earth's climate and that further human-induced climate change is inevitable.

The question is not whether climate will change in response to human activities, but, rather, where, when, and by how much. It's also clear that changes in temperature and precipitation will, in many regions of the world, adversely affect human health, ecological systems, and socio-economic sectors, including agriculture, forestry, water resources, and human settlement, thus affecting the economy and quality of life for this and future generations.

To limit the atmospheric concentrations of carbon dioxide to any level below three times pre-industrial would eventually require emissions to be well below today's level.

The good news is, however, that significant reductions in greenhouse gas emissions are technically feasible, due to an extensive array of technology and policy measures in the energy supply, energy demand, and land management sectors at little or no cost to society.

These reductions should not require the early retirement of capital stock, but should be taken in step with the normal timing of investments to replace infrastructure and equipment as it wears out or becomes obsolete.

Such measures will, however, require concerted R&D and demonstration programs to ensure these technologies penetrate the market place.

While fully recognizing that uncertainties exist, the IPCC concluded that human activities are increasing the atmospheric concentrations of greenhouse gases, and in some regions of aerosols.

The Earth's surface temperature is increased by about half a degree Centigrade over the last century, the sea level has increased 10 to 25 centimeters, and glaciers are retreating world-wide.

Models that take into account the observed increases in greenhouse gases and sulfate aerosols simulate the observed change in both surface temperature and its vertical distribution quite well.

Hence, IPCC concluded that the balance of evidence suggests a discernible human influence on the Earth's climate.

Without policies to mitigate greenhouse gas emissions globally, the Earth's temperature is projected to increase by between one and 3-1/2 degrees Centigrade by 2100, a rate faster than anything observed during the last 10,000 years.

We should note that these projections are about 25 percent lower than those reported in 1990, because of the inclusion of sulfate aerosols, the source of acid rain, in the projections.

In addition, we should note that our ability to predict changes in climate at the regional level still remains low.

Let me briefly summarize some of the consequences of climate change.

Human-induced climate change is an important new stress, particularly on ecological and socio-economic sectors that are already affected by pollution, increasing resource demands, and nonsustainable management practices.

Climate change is expected to lead to an increase in heat-related mortalities, as well as an increase in vector-borne diseases such as malaria, dengue, and then nonvector-borne diseases such as cholera.

Even though the effects of climate change on global food production may be small to moderate, there may be significant reductions in the tropics and subtropics, where many of the world's poorest people currently live.

Climate is projected to change at a rate rapid relative to the speed at which forest species grow, reproduce, and re-establish themselves.

Therefore, the species composition of impacted forests is likely to change. Entire forest types may disappear, while new assemblages of species and hence, new forest ecosystems, may be established.

Small islands and delta areas are particularly vulnerable to sea level rise. A one-meter sea level rise is projected to result in land losses ranging from one percent for Egypt, 17- 1/2 percent for Bangladesh, to as much as 80 percent for the Marshall Islands.

For example, in the absence of adaptation measures, tens of millions of people in Bangladesh would be displaced.

Now let me quickly discuss research priorities related to climate change.

To reduce the remaining scientific uncertainties identified by IPCC would require an integrated program, modelling, process studies, observations, and data management that address the following three main areas.

To continue to improve our ability to predict the impact of human activities on regional and global climate will require more accurate projections of future concentration of greenhouse gases.

An improved understanding——

Chairman WALKER. The time of the gentleman has expired.

Dr. WATSON. Fine. It will require, then, three major areas—improved understanding of how we affect climate change at the regional and global level, the consequences of climate change, and the technical feasibility of new measures.

In my opinion, the USGCRP is a well designed, scientifically driven program, but it will need to evolve in the future, just as it has in the past.

The program was initiated by President Reagan and further developed by both Presidents Bush and Clinton, with strong support of each of the administrations in Congress.

We believe that a scientifically based USGCRP can provide the enhanced scientific and technical information needed to guide effective public policy for climate change.

[The prepared statement of Dr. Watson follows:]

Statement of
Dr. Robert T. Watson
Associate Director for Environment
Office of Science and Technology Policy
Executive Office of the President
before the
Committee on Science
United States House of Representatives
March 6, 1996

Mr. Chairman and Members of the Committee:

I greatly appreciate being given the opportunity to discuss global climate change with you and your subcommittee. I am the Associate Director of the Environment Division in the White House Office of Science and Technology Policy. The Administration believes that this is an extremely important environmental issue of profound importance to this and future generations.

My testimony on the scientific knowledge of climate change is based on the latest findings of the Intergovernmental Panel on Climate Change (IPCC) Assessment, conducted under the auspices of World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP). I will discuss the U.S. Global Change Research Program (USGCRP) within the context of this international scientific consensus.

The IPCC reports were prepared by over five hundred authors and reviewed by over one thousand scientists from universities, government laboratories, industry, and other private sector organizations from developed and developing countries. They were subjected to both an "expert" review and an in-depth governmental review. The three *Summaries for Policymakers* and the Synthesis report, were ultimately approved line-by-line by governments and technical experts.

Two other international assessments, the *UNEP Global Biodiversity Assessment*, and the *UNEP-WMO Stratospheric Ozone Depletion Assessment* also provide a sound scientific basis for elements of the USGCRP, given the inter-relationship between these different issues.

Scope and Importance of the Climate Change Issue

While climate change is inherently a global issue, it is critical that we understand how climate will change at the regional scale and what the potential consequences may be. To be specific, we need to know how climate will change in the United States, what the consequences will be in different regions, and whether there are cost-effective solutions to slow climate change or adapt to it. Therefore, the scope of a comprehensive climate change

research program should evaluate:

- how human activities affect regional and global climate;
- what the potential consequences of climate change are; and
- the options for mitigation and/or adaption to climate change.

Current Understanding of Climate Change

The large majority of scientific experts have concluded, based on empirical evidence and simulations, that human activities have already affected the Earth's climate and that further human-induced climate change is inevitable. While a number of key scientific uncertainties remain, for the first time, the scientific community through the IPCC has stated "there is a discernible human influence on global climate." In other words, the question is not whether climate will change in response to human activities, but rather where (regional patterns), when (the rate of change) and by how much (magnitude).

It is also clear that climate change will, in many regions, adversely affect human health, ecological systems, and socio-economic sectors, including agriculture, forestry, fisheries, water resources, and human settlements. The good news is, however, that significant reductions in greenhouse gas emissions are technically feasible due to an extensive array of technologies and policy measures in the energy supply and energy demand sectors at little net cost to the economy. Such measures can slow climate change, but will require concerted R&D and demonstration to have these technologies penetrate the marketplace domestically or worldwide.

The following section summarizes the main IPCC conclusions for each of the three questions.

1. How do human activities affect regional and global climate?

Our ability to predict changes in climate at the regional level remains low, however we do know that:

- Human activities are increasing the atmospheric concentrations of greenhouse gases -- which tend to warm the atmosphere, and in some regions, aerosols -- which tend to cool the atmosphere;
- The Earth's climate is changing: the surface temperature this century is as warm or warmer than any other century since 1400 AD; the Earth's surface temperature has increased by about half a degree centigrade over the last century; and the last few decades have been the hottest this century;
- The balance of evidence suggests a discernible human influence on the Earth's

climate;

- Models that take into account the observed increases in the atmospheric concentrations of greenhouse gases and sulfate aerosols simulate the observed changes in both surface temperature and its vertical distribution quite well;

- In addition to changes in surface temperature, sea level is projected to increase by 15-95 cm by 2100, glaciers are retreating world-wide, and the incidence of extreme weather events is increasing in some parts of the world. Even with a stabilization of greenhouse gas concentrations in the year 2100, temperature would continue to increase for several decades, and sea level would continue to rise for centuries;

- The atmospheric lifetime of many greenhouse gases, coupled with the thermal inertia of the oceans, means that the warming effect of anthropogenic emissions will be long-lived -- even sharp reductions in greenhouse gas emissions would reverse warming very slowly; and

- Without global climate specific policies to mitigate greenhouse gas emissions, the Earth's temperature is projected to increase by between 0.8 to 3.5 degrees Centigrade by 2100: a rate faster than anything observed during the last 10,000 years; higher latitudes are expected to warm even more.

2. What are the potential consequences of climate change?

- Regional and global changes in temperature, precipitation, soil moisture, and sea level are expected to have wide-ranging and potentially adverse effects on physical and ecological systems, human health and socio-economic sectors, thus affecting the economy and the quality of life for this and future generations;

- Human-induced climate change is an important new stress, particularly on ecological and socio-economic systems that are already affected by pollution, increasing resource demands, and non-sustainable management practices;

- Most systems (human health, ecological and socio-economic systems) are sensitive to both the magnitude and rate of climate change;

- While impacts of climate change are hard to quantify because of uncertainties in regional climate projections, the fact that systems are subject to multiple stresses, and incomplete understanding of some key processes, we can project significant, often adverse affects on:
  - *human health*: there may be an increase in heat-related mortality, vector-borne diseases such as malaria, dengue, yellow fever, and encephalitis, and non-vector-borne diseases such as cholera and salmonellosis;
  - *food security*: significant regional dislocations could occur especially in the tropics

and subtropics, where many of the world's poorest people live; even though the effect of climate change on overall global food production may be small to moderate;
- *natural ecosystems*: the composition, geographic distribution and productivity of many ecosystems will shift as individual species respond to changes in climate. There will likely be reductions in biological diversity and in the goods and services ecosystems provide to society. For example, climate change is expected to occur at a rapid rate relative to the speed at which forest species grow, reproduce and re-establish themselves. Therefore, species composition of forests is likely to change, entire forest types may disappear, and new assemblages of species and hence new forest ecosystems may be established. Between one-third and two-thirds of vegetation types in forests are expected to change in response to a doubled-carbon dioxide climate;
- *human habitat loss*: small islands and delta areas are particularly vulnerable to sea level rise. A one-meter sea level rise is projected to result in land losses ranging from as little as 0.05% in Uruguay, to 1.0% for Egypt, 6% for Netherlands, 17.5% for Bangladesh, and to about 80% of the Marshall Islands. Large numbers of people will be affected, e.g., tens of millions of people in both China and Bangladesh.

In some cases, such as species loss, the impacts of climate change are irreversible. Developing countries are more vulnerable than developed countries to climate change because of their socio-economic conditions.

3. Are there technically feasible and cost-effective options to mitigate or adapt to climate change?

- Stabilization of the atmospheric concentrations of carbon dioxide at any level at, or below, three times pre-industrial levels will eventually require global emissions to drop below today's levels;

- Significant "no-regrets" opportunities, these which make sense for other reasons in addition to climate change, are available in most countries to reduce net greenhouse gas emissions. Furthermore, the risk of aggregate net damage due to climate change, consideration of risk aversion, and the precautionary principle provides rationale for actions beyond "no regrets;"

- A range of cost-effective technologies and policies can be used in both developed and developing countries to markedly reduce the net emissions of greenhouse gases from industrial, energy supply, energy demand, and land management practices. Projected greenhouse gas emissions can be reduced by 10-30% using current technologies over the next two to three decades at little cost;

- It is technically possible to realize deep emissions reductions in the energy supply sector in step with the normal timing of investments to replace infrastructure and equipment as it wears out or becomes obsolete; and

- Successful adaptation depends upon technological advances, institutional arrangements, availability of financing, technology transfer and information exchange;

- Climate change concerns must be incorporated into resource-use and development decisions.

- Flexible, cost-effective policies relying on economic incentives and instruments, as well as coordinated instruments, can considerably reduce mitigation and adaptation costs.

Research Priorities Related to Climate Change

This section will highlight some of the highest priority areas of research for each of the three major areas/questions discussed above.

1. What is the impact of human activities on regional and global climate in the context of natural climate variability?

There are a number of major challenges facing the scientific community if we are to improve our ability to predict future changes in regional and global climate. We need to:

- develop more accurate projections, by sector and region, of future emissions of greenhouse gases in order to improve our projections of their future atmospheric concentrations, and subsequent warming;

- conduct further research on the carbon cycle in order to more accurately quantify the atmospheric lifetime and future atmospheric concentrations of carbon dioxide, hence improving our projections of additional warming;

- extend our understanding of the past, current and future distribution of aerosols and their radiative properties, hence develop projections of regional impacts;

- improve our understanding of the response of the climate system, regionally and globally to additional radiative forcing, with emphasis on water vapor and clouds, and the exchange of energy between the atmosphere and oceans;

- develop more reliable transient ocean-atmosphere climate models in order to quantify the rate and regional distribution of climate change, and the future location, severity, and frequency of extreme events;

- continue to quantify natural variations and long-term trends in climate variables on a variety of spatial and temporal scales using the paleoclimatic record and a variety of space and non-space observational techniques;

- continue to combine observations and models to establish the cause of long-term trends in climate variables.

2. What are the potential consequences of climate change?

To gain an improved understanding of the potential consequences of climate change, in the context of other stresses, will require a significant improvement in our ability to predict climate change at the regional level (including the location, severity, and frequency of extreme events), an improved understanding of key processes (including ecological, social, and economic), and an improved understanding of other stress factors such as air and water pollution, the demand for natural resources, and unsustainable management practices. We need to:

- Improve our understanding of the response of ecosystems (distribution, function and composition) to changes in temperature, water availability, and atmospheric composition (e.g., carbon dioxide).

  More specifically:
  - How will ecosystem functions such as purifying and storing water, regulating water runoff, controlling coastal erosion, and regulating climate be affected by climate change?
  - At what rate can species re-establish themselves in new locations as climatic conditions change, and can human interventions be developed to assist this process?
  - How will increased levels of atmospheric carbon dioxide -- which has been shown to increase growth of some important plant species under laboratory conditions -- affect whole ecosystems over long periods of time?

- Investigate how global change will affect employment opportunities, economic growth, national and international trade flows, and other social and economic characteristics that support the communities which make up the fabric of U.S. society.

  In particular, we need to understand how:
  - Agricultural and forest productivity will be affected by changes in climate and atmospheric composition, taking into account changes in the ranges and incidence of pests, the costs of adjusting cropping and forestry systems so that they are optimized with respect to new conditions, and the opportunities for growing new crops and changing land use;
  - Water resources will be affected by changes in temperature and precipitation; how these will affect the ability of water resource managers to cope with increased demand for freshwater, and the implications for planning and construction of water catchment and storage systems;
  - Climate change and sea-level rise will affect coastal systems, including commercial fisheries and buildings, and other infrastructure located in

vulnerable coastal regions;
- Changes in extreme weather events will affect the insurance and financial insurance industry; and
- Changes in climate will affect human health, in particular how the range of vector- and non-vector-borne diseases will change in response to changes in climate variables.

3. Are there technically feasible and cost-effective options to mitigate or adapt to climate change?

Assessing the technical feasibility and cost-effectiveness of options to mitigate or adapt to climate change will require an evaluation of the technical potential of mitigation technologies, their cost-effectiveness, and the barriers to the diffusion of these technologies into the market place for each of the key sectors including: energy supply (including fossil, renewables, and nuclear); energy demand (including transportation, buildings, industry and utilities); and land-use practices (including carbon sequestration in vegetation and soils in rangelands, agriculture and forests). This will require emphasis on:

- The development of improved technologies, including;
  - more efficient end-use energy technologies in all sectors, including transportation, buildings and industry;
  - non-greenhouse gas emitting supply-side technologies including nuclear and renewable energy technologies, especially biomass, solar thermal and electricity, wind and micro-hydropower; and
  - more efficient conversion of fossil fuels.

- Understanding the major constraints which limit the commercialization of emerging "cleaner" technologies, and identification of the opportunities that can be used to overcome them;

- Understanding the potential to reduce emissions and increase storage of carbon in grasslands and in the agriculture and forestry sectors, taking into account the relative benefits and costs of reducing net emissions by changing agricultural practices or establishing new forests.

Scope of the U.S. Global Change Research Program and Related Programs

The U.S. Global Change Research Program (USGCRP), which has a broader scope than global climate change, is a critical tool in addressing the uncertainties discussed above. It is designed to address a number of highly inter-related global environmental issues, including global climate change, seasonal to inter-annual climate fluctuations, stratospheric ozone depletion, changes in tropospheric chemistry, and land-use/land-cover changes. In addition, the USGCRP is closely coordinated with other research programs that study related

environmental issues such as biological diversity, resource use and management, air quality, water resources, and natural disasters. This coordination is achieved through the Committee on Environment and Natural Resources (CENR) of the National Science and Technology Council (NSTC).

Importance of the Federal Government Role in USGCRP

Significant progress in understanding global climate change (and the other global environmental issues as mentioned above) has been made over the past decade or so because of the strong bipartisan commitment to the USGCRP. This was a program initiated by President Reagan and further developed by President Bush and Clinton with strong support from Congress. All three Administrations and Congress recognized the social and economic importance of the global environmental issues encompassed by the USGCRP. There was general agreement that enhanced scientific understanding is essential for the development of appropriate, cost-effective options to mitigate or adapt to climate change, ensure environmental protection, protect the health of our citizens, and ensure that economic and national security are not jeopardized.

The Federal government, in conjunction with the private sector should, and must, continue its commitment to a better understanding of our global environment. While the private sector has some limited research capability in the area of climate change, only the Federal government, in strong collaboration with its colleagues in academia, can adequately address the breadth of this critically important social issue.

Effective international cooperation is needed as well. The USGCRP provided most of the critical scientific information needed to develop national and international policies for safeguarding the Earth's protective ozone layer. Only a well-funded, scientifically-based USGCRP can provide the enhanced scientific and technical information needed to guide effective policy formulation for coping with climate change.

Implication for the Current USGCRP

The USGCRP is a well designed scientific program that is providing high quality policy-relevant information. During the last decade or so the program has made a large number of significant scientific advances and demonstrated flexibility in responding to new scientific challenges. Let me provide just two examples of scientific progress and programmatic responsiveness -- there are dozens more:

- In response to the discovery of the spring-time Antarctic ozone hole, USGCRP agencies (NASA, NOAA and NSF) established a coordinated program of laboratory studies, theoretical modeling activities and observational programs (ground-based, balloon, aircraft, and satellite) to study this phenomenon. Within three years of its discovery the USGCRP had established its cause: long-lived industrially produced chlorine- and bromine-containing chemicals. It also established the cause of the mid-

and high-latitude loss of stratospheric ozone, and quantified the impact of stratospheric ozone depletion on the Earth's climate.

- In response to the 1990 IPCC Assessment Report which highlighted the potential importance of sulfate aerosols, several USGCRP agencies established research programs to better understand the role of aerosols in the Earth's climate. While key uncertainties still remain, these programs have led to a considerable improvement in our understanding and important convergence between observations and model simulations.

The scope and balance of activities in the USGCRP will need to continue to evolve in the future just as they have in the past. This program must, and does, devote significant resources to space and in situ observations and data management in addition to process studies, modelling and analysis. To understand climate change, both natural and anthropogenic, USGCRP will have to place an increasing emphasis on understanding the consequences of climate change at the regional level and on some key socio-economic aspects, including the costs and benefits of reducing greenhouse gas emissions. To perform such an analysis will require, among others, improved techniques to value biological resources and biodiversity, both in terms of market and non-market value, and understanding barriers to the diffusion of technologies into the market place.

We need to maintain the high quality science-driven USGCRP that emerged during the Reagan and Bush Administrations and which has been strongly supported by the Clinton Administration. The need to observe, understand and predict the Earth system has been given even greater emphasis by the latest set of findings from the IPCC. In particular, we need to improve our ability to predict climate change at the regional level, and we need an increased emphasis on understanding the consequences of climate change. The latter will require more research into basic ecological processes, development of more sophisticated modeling frameworks, and the establishment of improved capabilities for ground- and space-based monitoring and data management. In addition, we need better databases for vulnerability assessment and planning of adaptation, including data on population trends, resource utilization, and the value of natural and economic resources. The development of a broad range of sectoral and integrated modeling capabilities is also required to determine the potential significance of global change for the United States and the world.

Summary

The scientists of the world have agreed that climate is changing and that there is a discernible human influence. However, policymakers are faced with responding to the risks posed by anthropogenic emissions of greenhouse gases in the face of scientific uncertainties about the details -- the magnitude, regional impacts, and rate of climate change. Climate-induced environmental changes cannot be reversed quickly, if at all, due to the long time scales associated with the climate system. Ultimately, it is not for scientists but rather for

decisonmakers to decide what "dangerous" means under the Framework Convention on Climate Change.

Decisions taken during the next few years may limit the range of possible policy options in the future because high near-term emissions would require deeper reductions in the future to meet any given target concentration. Delaying action might reduce the overall costs of mitigation if potential technological advances are vigorously pursued in the interim, but could increase both the rate and the eventual magnitude of climate change, and hence the adaptation and damage costs.

Policymakers will have to decide on the degree to which they want to take precautionary measures by mitigating greenhouse gas emissions and enhancing the resilience of vulnerable systems by means of adaptation. Uncertainty does not mean that a nation or the world community cannot position itself better to cope with the broad range of possible climate changes or protect against potentially costly future outcomes. Delaying such measures may leave a nation or the world poorly prepared to deal with adverse changes and may increase the possibility of irreversible or very costly consequences. Options for adapting to change or mitigating change that can be justified for other reasons today (e.g., abatement of air and water pollution) and make society more flexible or resilient to anticipated adverse effects of climate change appear particularly desirable.

Finally, it is precisely the fact that aspects of global climate change remain uncertain that argues most strongly for a comprehensive research effort. Dealing with the issue of climate change requires a greater understanding of the Earth system. The complexity of the Earth system, a complexity agreed on by all those who have testified today, makes this an immense scientific challenge. I think nearly all the panelists would also agree that strong Federal science programs and Federally funded University research are critical to meet this challenge. The sheer magnitude of this task, combined with the seriousness of the potential consequences of climate change, provide a clear justification for the maintenance of a strong national research program focused on this issue.

Chairman WALKER. Thank you.
Dr. Michaels?

STATEMENT OF DR. PATRICK MICHAELS, DEPARTMENT OF ENVIRONMENTAL SCIENCES, UNIVERSITY OF VIRGINIA, CHARLOTTESVILLE, VIRGINIA

Dr. MICHAELS. Thank you. I would hope that I get a few seconds while we figure out how to get the screen down.

Chairman WALKER. I'm going to do that.

Dr. MICHAELS. Okay. That's magnificent. I'm going to switch microphones, if you don't mind.

Well, I hope you have your binoculars with you. Sorry about this. These are things that are beyond our control.

I would like to address the issue of climate change, if I could, from perhaps a slightly different perspective than Dr. Watson.

But I would like to say that this is a hearing about gathering facts, a hearing about what we understand about climate change and what we need to know in the future.

You can put me down as one scientist who believes firmly that in the collection of facts on the issue of global climate change and believes that in the future, we should do whatever we can to attempt to improve our understanding of the atmosphere and our ability to model it.

In my five minutes, I'd just like to give you seven examples of how the facts have changed the issue of global climate change in the last five years. I think they have changed the scenario of climate change from what I would call the dangerous scenario to the moderate climate change scenario.

And I offer you as an example this chart right here, which compares the performance of the general circulation climate model that was cited very heavily in the report for the 1992 earth summit that was created by the IPCC.

These are the temperatures that run out of that model, if you run it with the carbon dioxide concentrations that have evolved over the 20th century, and these are the temperatures in the northern hemisphere underneath.

There is a clearly a mismatch here. This mismatch was pointed out by the data. It was pointed out by a data stream that we think may be degrading.

In the United States, we have problems now with our large-scale temperature network. And I urge this Committee to do everything they can to make sure that that network remains very high quality.

When the disparity was pointed out between the climate models and the observed temperature data, it was thought that sulfate aerosols were a sufficient explanation for the lack of warming.

Here is the satellite temperature history that Dr. Christy is going to show you very soon from the southern half of the planet. There are no sulfate aerosols to speak of in the southern half of the planet. Yet, this half of the planet is in fact cooling significantly.

Sulfate aerosols cannot be the cause of the cooling in the southern half of the planet.

And the satellite records that we have are exceedingly accurate. This is the comparison of the temperature between 5,000 and

30,000 feet, as measured by weather balloons and as measured by satellite.

There is no doubt that it is finding a cooling in the southern hemisphere.

And finally, we contest whether sulfates in fact are responsible for the failure. In only one item in the scientific literature has anyone ever asked the following question—were the models that predicted the large warmings failing because they didn't have sulfates in them?

I know I have very, very few seconds left, and I will merely tell you that we can examine that mathematically and we could look for where the models do very well, which would be the green light, and where the models do make mistakes, numbered categories 2, 3 and 5.

This is a place with no sulfates whatsoever. The models should do very well here. All they do is either predict no change where no change was observed, predict change that didn't occur, or predict change that was opposite to what occurred.

And here is the model where the sulfate effect should be the greatest. The large green bar is the largest, best performance in the entire model. When you test the model without sulfates in it, it performs best where the sulfates are.

Ladies and gentlemen, the thing that has caused the fever in this model, or the illness in this model, is not sulfates.

So now we have a new explanation, that somehow ozone depletion in the stratosphere is responsible for the failure of the warming. And that explains the reason that the satellite temperatures do not show warming while the surface temperatures do.

Well, this is a graph of the satellite temperatures, which are the open circles, and the ground-based temperatures, which are the closed circles on the right. The areas of ozone depletion are the lower southern hemisphere, and it turns out the records match up perfectly.

And there's some depletion in the high northern hemisphere.

In the equator, in the tropical regions, there is no stratospheric ozone depletion. And yet the model, the temperature in the satellite and the temperature of the surface do not match.

Ozone is not going to explain the disparity between the satellite record and the surface temperature, although that is going to be the next best explanation.

I would also like to caution you that we've heard about extreme rainfall events increasing. I'd just like to show you a little bit of data on that, in closing.

This is a graph of the percent of rainfall from rainstorms that are more than two inches and it's going up. This is from Tom Karl. This was all over the newspaper as a sign that this was caused by the greenhouse effect. The largest increase occurs from 1930 to 1950, which is long before the greenhouse effect could have done this.

This is typical of what we see.

We hear stories about bad things being caused by climate change, and when we examine the data closely and do the true scientific test, did the change occur because of the greenhouse effect? In this case, it does not fulfill it.

Finally, there's the matter of exaggeration. Rainfall events of more than two inches are not torrential. In fact, 70 percent of all rainfall that is more than two inches turns out to be less than three inches in the summer.

Almost all of those rainfall events are beneficial.

Well, I leave you with the flavor of this. I'm sure we're going to discuss a lot more of this later. I would merely like to say that the reason that all these facts have come out is because of data, because people were very, very careful to keep data sets intact.

We need to do this in the future. We need to take a look at our sensing from the remote sensors up in space. And I'll be happy to talk about this later. Thank you.

[The prepared statement of Dr. Michaels follows:]

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Testimony of Patrick J. Michaels, Department of Environmental Sciences, University of Virginia, to the Committee on Science, U.S. House of Representatives, March 6, 1996.

This text represents the personal testimony of Patrick J. Michaels and is no official representation of the University or Commonwealth of Virginia. This testimony is tendered with the traditional protection of academic freedom.

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I have been asked to offer my testimony on the state of our knowledge about global change, including recent developments in the field, and on the priority for data collection relating to this important problem.

In science, data are the philospher's stone that confirm or reject the hypotheses of theoreticians. In the science of global warming, it is the data that have moved the theoretical models of climate change from prognostication of rapid and disastrous warming, to reduced and slower change much more consistent with a "moderate", rather than "dangerous" synthesis of the issue.

It is also the data that demonstrate that current hypotheses as to the cause of failure of the climate models that based the 1992 Framework Convention on Climate Change are themselves likely to be incorrect. And it is the data that demonstrate that statements ascribing increases in large rainfall events in summer to changes in the greenhouse effect are not supported.

In my testimony I will cite seven examples of how climate data have changed the paradigm on climate change from "dangerous" to "moderate". In each example, I cite the source of data in order to underscore the need to continue to monitor and collate important environmental information.

At the outset, it is worth noting that the purpose of the Framework Convention, according to the treaty itself, is to "prevent dangerous anthropogenic interference in the climate system".

Even though accurate environmental data is essential, it is also, in some cases, expensive. There may be a novel solution to the problem of funding climate change research that relieves some of the public burden and shifts the costs to some of the fundamental interest groups concerned with this problem. I note this in a final comment.

1. Climate models that were heavily cited as providing scientific basis for the Framework Convention were wrong.

In 1992, the United Nations Intergovernmental Panel on Climate Change published a "Supplementary Report" prepared specifically to provide the technical background for the 1992 Framework Convention on Climate Change. Unlike their previous (1990) report, which relied on climate models that "instantaneously", and therefore unrealistically, doubled their carbon dioxide greenhouse effect, the 1992 report used models that gradually increased the greenhouse effect and also included a more elaborate calculation of the ocean-atmosphere interaction. The net warming predicted by these models for doubling carbon dioxide generally ranged between 4 and 4.5°C.

The models could be checked in a variety of ways. One simple test is to calculate the global mean temperature change that would be expected by the models for current changes in the greenhouse effect. As early as 1987, T.M.L. Wigley calculated that the mean planetary warming to then should have be 1-1.5°C; the observed value of 0.45° valid at that time indicated that errors, averaged globally, were in the 200-300% range. Using the results of the transient coupled ocean-atmosphere model of Manabe et al. (1991) , and allowing the model even more time to warm than was allowed by reality, I found that the error was of the same magnitude found by Wigley. This result was eventually published in the *Bulletin of the American Meteorological Society* and elsewhere in the scientific literature.

Parenthetically, I must state that it was common knowledge in the modelling community that, at the time of the 1992 *Supplementary Report*, the models were making errors this large; As evidence for this I have appended the reviews of my original manuscript that was sent to *Science*. Nowhere did the one negative reviewer deny the reality of the calculations; rather, it was stated that "Those who work with GCMs [climate models] know the problems associated with their models". Somehow, a public airing of the overprediction of warming was apparently inappropriate but nonetheless well known.

The most recent quantitative argument concerning the models of the type featured in IPCC (1992) is by Mitchell (1995), and indicates that the current error in those type of models is a minimum of 160% and a maximum of 360%.

Data: The data for these analyses came from ground-based weather stations. In the United States, we are currently changing the measurement systems and there is concern that the "newer" measurements may be incompatible with older ones. Research and data collection that preserves the integrity of the land based climate record must be in the class of highest priority.

2. The failure of the earlier forecasts is not explainable by sulfate aerosol.

The 1995 IPCC "Second Assessment" builds the paradigm that the cooling effect of sulfate aerosols is sufficient to explain the disparity between warming predicted by models in the 1992 *Supplementary Report* and observed temperatures.

The logic employed by IPCC (1995) in making this assertion is questionable. While models that attempt to mimic the effect of sulfate aerosols *must* provide a better explanation for the lack of warming, that does not imply that aerosols are a sufficient cause. In fact, addition of any mathematical parameter that reduces radiation reaching the ground will simulate less global warming and therefore appear to be a better model than those employed in 1992.

A more logical defense of the sulfate hypothesis would be to take the *non-sulfate* models and to see if their failure was minimized in large areas where the sulfate effect would be minimized. I have formally tested this hypothesis (Michaels et al., 1994) and found that the nonsulfate models performed *best* where the sulfate cooling was supposed to be greatest.

Another test would be to simply compare the Northern and Southern Hemispheres. The Southern half of the planet is virtually sulfate-free. And yet Satellite measured temperatures are falling, both in absolute value and in comparison to the Northern Hemisphere, which is the half of the planet that should be relatively cooled by sulfates. The change that there in fact is no negative trend in the southern hemisphere satellite data is less than 1 in 10,000.

Data: The data sources consist of the surface temperature records noted above and temperatures sensed by microwave-sounding satellites. While these are NOAA platforms, the data capture and analyses are performed by NASA. This system is currently threatened by machine failures related to expected lifetimes. Maintenance of this datastream is of the highest priority as it provides strong and objective evidence against the "dangerous" warming paradigm.

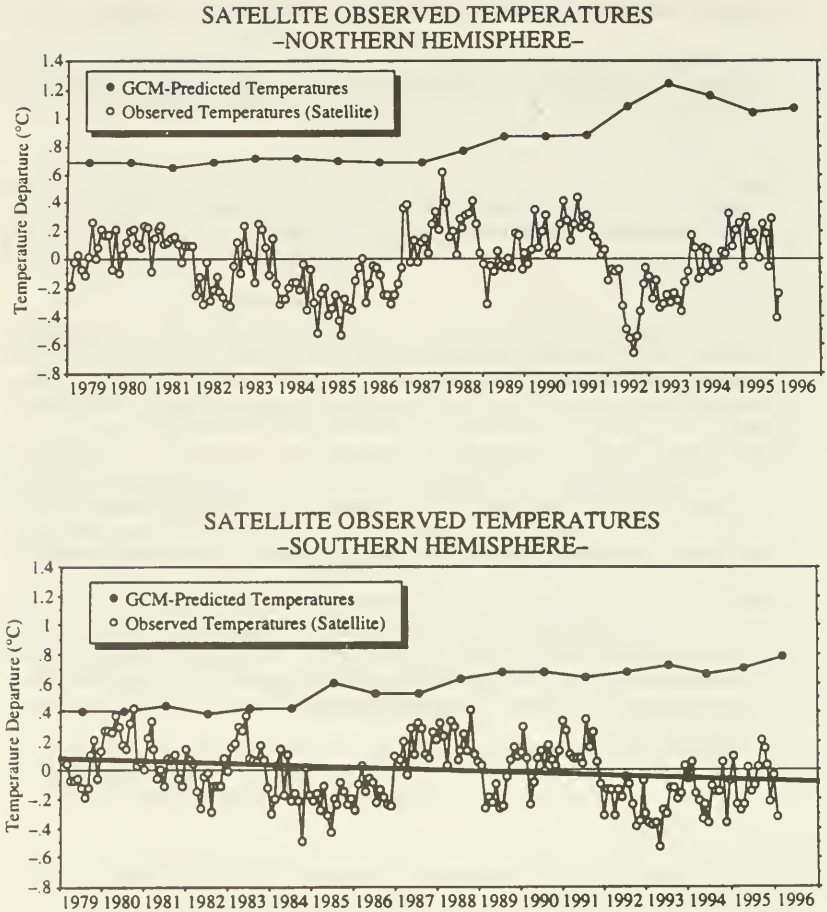

Figure 1. Satellite-sensed temperatures compared to relative warming predicted by a model typical of those cited in the 1992 IPCC *Supplementary Report* prepared for the Rio Earth Summit. The negative trend in the sulfate-free Southern Hemisphere is highly significant.

3. Stratospheric Ozone depletion does not explain the lack of warming.

In response to the first two items noted in this testimony, a novel explanation is emerging: that stratospheric ozone depletion explains the lack of warming obvious in the satellite data, and also explains the disparity between ground-measured temperatures and the satellite data. NASA modeller James Hansen noted this in a January report about satellite temperatures in the *Washington Post*. Last week, climatologist Phil Jones noted the same in a presentation at the head office Australian Meteorological Bureau in Melbourne.

Ozone depletion is greatest in the high latitudes, particularly in the Southern Hemisphere, and there is virtually no depletion in the tropical half of the planet. Thus the disparity between ground and satellite temperatures should be greatest in the high latitudes and least in the lower latitudes. *The opposite is true.* Satellite and ground-measured temperatures match very well in high latitudes and mismatch in the tropics.

A parenthetical argument has been somehow the satellite data are in error in the free atmosphere. In fact, on a global basis, the agreement between satellite data and the mean temperature sensed by weather balloons in the layer between 5,000 and 30,000 feet is truly remarkable, with a statistical correspondence of nearly 95%.

Data: In addition to the two data sources mentioned previously, this analysis uses the global weather balloon (radiosonde) network data that is collated in large part by NOAA scientists and the National Climatic Data Center. Maintenance and analysis of this network at the highest level of quality is clearly as high a priority other data priorities noted above.

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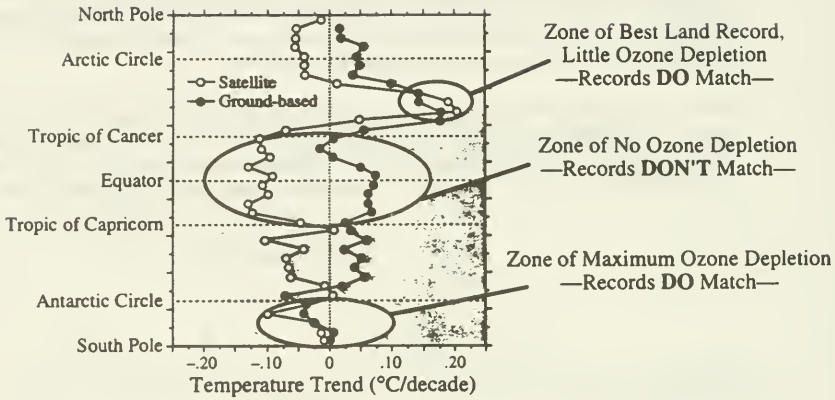

Figure 2. Area-weighted temperatures from the ground based (solid circle) and satellite (open circle) records.

4. The most likely explanation for the failure of the models is in their forecast of temperature in the zone from 5,000 to 50,000 feet.

All transient climate models, including those modified with sulfate aerosol, predict a rather smooth and consistent warming of the entire troposphere, or bottom 50,000 feet of the atmosphere. It is apparent that the atmosphere has cooled above 30,000 feet and that there is no net change in the last 20 years in the region between 5,000 and 30,000 feet. There was a sudden jump in this layer temperature in 1977; no change was noted prior to then, either.

The implications of the behavior in these layers is profound. Everything else being equal, the cooling from 30,000 to 50,000 feet increases the vertical transport of moisture in the atmosphere and could be responsible for observed increases in large-area cloudiness. In turn, the increases in cloudiness could explain the overall lack of warming and its distribution primarily into the winter and night; in the region of the planet that has shown the most warming--Siberia--the ratio of winter to summer (which is, essentially, night (or low sun)-to-day) is approximately 4.2 to 1. The primary climatic effect would be two slightly lessen the severity of the coldest airmasses in the Northern Hemisphere.

Several scientists, including Dr. Lindzen on this Panel, have hypothesized that model calculations of the vertical distribution of heat in the atmosphere are likely to be wrong or at least unreliable; the failure of the models to even simulate the *sign* of observed changes in the last two decades bears strong witness to this hypothesis.

Data: While there are many hypotheses concerning the inaccuracy of the prediction of vertical temperature change, data required to resolve this will come from atmospheric sounding devices such as weather balloons and satellite profilers. These should therefore by high priorities for support.

5. LACK of data can cause embarrassing errors.

In early January we were treated to a number of stories stating that ground-based thermometers indicated that 1995 was the warmest year in the instrumental record. In fact, the temperatures used to make this calculation only included data through November, 1995, and an assumption that December temperature departures from normal would be the same as they were for the rest of the year. This temperature history was complied by Phil Jones of the University of East Anglia.

As noted in the satellite data (Figure 1) , December temperature departures from the mean in fact reflected the largest single one-month *drop* in the entire record for the Northern Hemisphere, declining by 0.72° from November.

These types of errors could be expected to propagate throughout the climate measurement system if surface data collection and analysis is allowed to degrade.

6. Increases in strong summer rainfall are not explainable by climate models, and are more likely to have been beneficial rather than "dangerous".

In his March 17, 1995 "Earth Day " address at George Washington University, the Vice-President noted that, with regard to global climate change, "torrential rains have increased in the summer during agricultural growing regions".

The source for his statement was a then-unpublished manuscript by Thomas Karl et al. that showed a statistically significant, but very small increase in the percent of United States rainfall that occurred from rainstorms that produced at least two inches of rain in 24 hours. The equivalent change is that, on the average, there is now one more day in every 730 days in which it rains more than two inches.

Examination of Karl's own graphics indicates that the largest increase in this parameter took place between 1930 and 1950, or prior to 70% of the human-induced changes in the greenhouse effect. Ascribing this change to the greenhouse effect is therefore dubious at best.

Perhaps as important, the vast majority (70%, nationally) of summer 24-hour rainfall that is greater than two inches is *less* than three inches. It is very hard to entertain the notion that a 2-3 inch rain in summer is "torrential", and, *in toto* hardly a "dangerous" change in climate. At that time of the year, all major agricultural regions of the U.S. are, on the average, losing more moisture to evaporation than they gain from rainfall, and this rain is much more likely to be welcomed by farmers than feared.

Data: The data for this study came from the cooperative-observer network of raingauges, maintained by the National Climatic Data Center. Maintenance of this high-quality record is a very high priority. Recent attempts to augment this history with satellite measurements have met with limited success, but it is nonetheless important to develop a system that reliably provides global monitoring of rainfall, especially over the ocean and in unpopulated regions. This should also be a very high priority.

7. Model calculations have made large errors in projections of jet stream positions.

These areas have been discussed in the testimony of Robert Davis.

Data: The data required to examine these aspects of model performance include weather balloon soundings and ground-based rainfall measurements. As noted above, these can and should be augmented with an improved remotely sensed rainfall network as well as satellite-based vertical profilers of atmospheric temperature, pressure, and moisture.

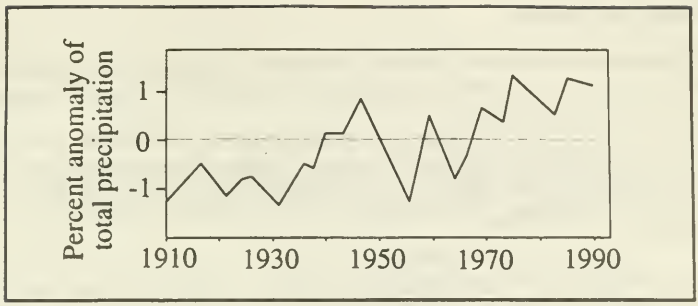

Figure 3. Plot of the increasing percentage of rain falling from storms of two inches or more. The large increase was before the greenhouse effect had changed very much.

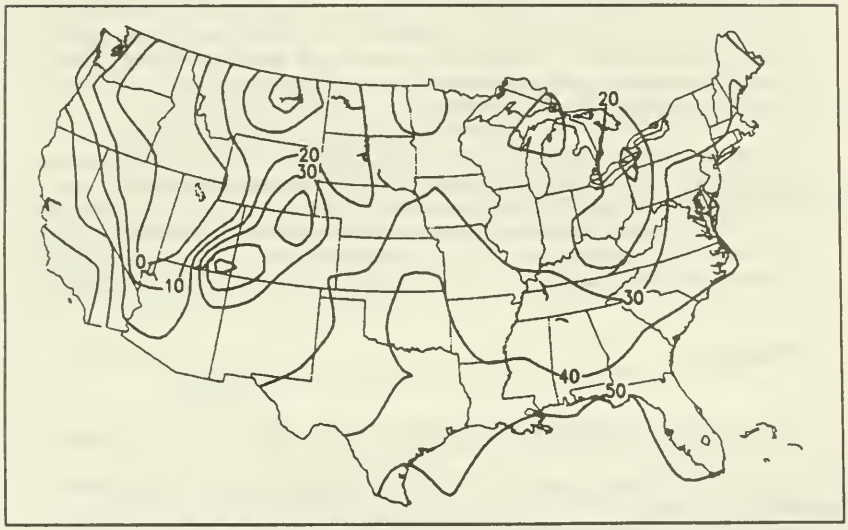

Figure 4. Percent of rain from storms of greater than two inches falls from storms that are more than three inches. Approximately 70% of two inch storms produce less than three inches, making them hardly "torrential" [see text].

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Thoughts on funding

It is clear that we live in an era of declining federal financial support of many aspects of the nation's life. One cannot expect that federal research budgets will be immune to this trend.

In the area of global climate change, there is little doubt that several public servants feel very strongly that research indicates the "dangerous" view of climate change is more likely than the newer, "moderate" synthesis. Thus the federal research presence in this area will always raise suspicions--real and imagined--that the funding process has become politicized.

One can change neither this perception nor the ambitions of those who champion any point of view; rather, the best tactic may be to admit to the reality of the problem and purposefully attempt to broaden the research base to explicitly include as providers some of the communities that are especially concerned with the issue of climate change.

Might it not be appropriate, in this era of declining funding, for interested parties *other* than government to begin to assume some of the research burden? I am referring specifically to two groups with considerable resources: industry and the environmental community. Perhaps you can develop a mechanism where both of these groups explicitly demonstrate financial support for research on climate change, and then the federal outlay is reduced an equivalent amount. I do not know much of these matters, but I suspect there are some incentives that can aid in this process.

This proposal would have the effect of maintaining financial support for research on climate change while broadening the base of support. There is no known constitutional fiat that I know of that requires that the federal government be the sole provider of funding for climate change research, even though that is virtually the case today. And further, there is demonstrable evidence that removal of the "monopoly" provider status of the federal government may in fact result in a more diverse, and therefore healthy, research culture on this important issue.

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May 3, 1995

ATTACHMENT #1. Entire reviews sent to author of a *Science* manuscript, noting that the error in models of the type that based the Rio Treaty was large and growing.

SCIENCE

Author/Title Michaels, P. J. "Global Failures: Transient Forecasts of Enhanced Greenhouse Warming" RE931811

Comments for transmittal to author
(Please restrict comments regarding acceptance of the paper to space below the perforation)

This paper addresses an issue that has not been adequately treated in the broad public discussion of "global warming," i.e. "How good are the models that represent the formally stated "greenhouse" hypothesis?" The results given here are definitive for one of the set of such questions. They should be published.

Unfortunately the English is so opaque that only a specialist can really tell what the authors say. A few hours spent on improving the English would be well worth the effort - for the message needs saying clearly.

Author/Title Michaels, P. J. "Global Failures: Transient Forecasts of Enhanced Greenhouse Warming" RE931811

Comments for transmittal to author
(Please restrict comments regarding acceptance of the paper to space below the perforation)

This is a very misleading paper. The reason Manabe et al., and others, have been performing coupled atmosphere-ocean GCM simulations is to understand the transient behavior of the models. These simulations are not intended to be "transient forecasts". Nor is it reasonable to assume that the past 100 year temperature record is due solely to anthropogenic causes. Natural variability is certainy present, and the model could not replicate this because of the way it has been initialized.

Those who work with GCMs know the problems associated with their models. This paper is not an objective critique of those problems.

Chairman WALKER. Thank you. Dr. Lindzen?

STATEMENT OF DR. RICHARD LINDZEN, SLOAN PROFESSOR OF METEOROLOGY, CENTER FOR METEOROLOGY AND PHYSICAL OCEANOGRAPHY, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, CAMBRIDGE, MASSACHUSETTS

Dr. LINDZEN. Thank you, Mr. Walker, members of the Committee.

I'm happy to be here to discuss the issue of global change in the context of Mission to Planet Earth.

In any event, I will keep my remarks brief. I won't go to my transparencies. But I will say that, as my testimony, my written testimony, points out, that there is a great deal of progress going on in this subject and it's coming from something that was, I think, rather glibly treated by Bob Watson.

I think most of my friends in academia and philosophy of science smirked when they heard a statement that we're now confident that man has contributed something to climate change. The only issue now is how much, where and when.

Long ago, it was established that unless you answered those, you're not dealing with science. And answering those requires prioritization, which is what we're trying to deal with here.

For example, and I hate to draw in numbers, but doubling carbon dioxide will change a flux by four watts per meter square. As I say, don't worry about what that means, but that's a number.

You would think that in prioritizing our dealing with the effect of that number, we'd compare with it. And yet, if one looks at the IPCC, one finds no relation. There's emphasis on terms that are a quarter-watt per meter squared. There's dismissal of terms that are a hundred watts per meter squared.

Unless we prioritize in that way, we're not likely to make progress.

Fortunately, and this is crucial, despite programs, despite national plans, despite organizational patterns, scientists, as a rule, like to know the answer. And although it's been emphasized they're unlikely to work as hard if they're not paid as if they're paid, it is astonishing how much scientists will do even if they're not paid.

In this connection, the issue of how much climate change will occur from a doubling of CO2 actually depends a great deal on something called the sensitivity of the climate to radiative forcing.

It was recognized by a number of us over many federal labs, over university labs and so on, that this is a measurable quantity. This is an issue that can in significant measure be settled.

It won't settle all of climate, but it will tell us whether we have a big problem or a small problem. And the preliminary results from Ming-Da Chou, from others, from Roy Spenser at NASA, Marshall, are that it's going to be a much smaller problem than thought.

Now, there's lots of stuff I'll discuss, but I'll skip it in order to just summarize a few things.

It is essential in dealing with global change science to distinguish between the health of the science and the health of the programs. I'm going to move back to the earlier session.

I was at the LaJolla meeting that responded to Representative Walker. There came out of that meeting a support for AM-1, PM-1, and a modified CHEM-1.

But in the E-mail discussion, in order to get a final version of that report, there was an insistence on one feature and that is, in the final version that was sent to you—and that was that after AM-1, PM-1, and CHEM-1, it's up for grabs, that there can't be the follow up to 2020.

I think Charlie Kennel supported that.

What happened was there was a recognition that a community exists that would be demoralized if you just ditched it. But there was also a lot of discussion about the fact that after all the rescopings and cut-backs, it was hard to point to a loss of science.

There's an historian of science at Columbia University who came up with a really disturbing result, unless you want to cut budgets. And that was the output of science seemed to go as the third power of the investment.

That is to say, you cut in the investment by the factor of eight and you only cut the science by a factor of two.

In any event, we've often heard that science is the foundation of EOS——

Chairman WALKER. The time of the gentleman has expired.

Dr. LINDZEN. Okay.

Chairman WALKER. It goes real fast.

Dr. LINDZEN. Okay. Science wasn't discussed much. I would also turn to a political system. The health of science absolutely requires that we realize that science isn't advocacy.

Science that is healthy involves an intense concentration on something called falsification. Whatever idea comes up, you try to find out what will see if it's false.

What we're having with Mission to Planet Earth is defensive concensi, and this is a sign of poor health.

The last thing I'd like to say is, and this is quixotic, science functions best when it has the trust of society to freely pursue questions and insights as they arise. Science cannot be dependent on fear. There can't be good science if the consequence of answering questions is that the support disappears.

Thank you.

[The prepared statement of Dr. Lindzen follows:]

Testimony: House Committee on Science, March 6, 1996

Richard S. Lindzen, MIT

Current State of Knowledge in Global Change

Representative Walker , Members of the Committee,

I am grateful to the committee for the opportunity to express my views on the science of Global Change, but I must immediately qualify my remarks by admitting that the subject is so broad that I cannot pretend to any degree of comprehensiveness. My remarks represent my personal observations, and are colored by my own research interests which focus on the theoretical foundations of our understanding of climate. I hope I may be forgiven if I claim that this topic is at the foundation of the broader topic.

My remarks are both positive and negative. On the positive side, I am happy to report that there is substantial progress being made in dealing with fundamental questions such as

- What is the sensitivity of climate to changing CO_2?
- What are the mechanisms by which climate change can occur?

I will discuss these matters shortly. However, I will begin with the more negative issue: namely, it is not obvious how either the USGCRP or MTPE have explicitly contributed to this progress. In order to explain this, one must briefly consider the historical, political, and institutional problems that have beset Global Change research. I will begin by considering EOS. This was a massive program which began under some remarkable circumstances. One might naively suppose that such an ambitious program was being undertaken because the science had matured to the point where resources were needed to make progress in settling well focussed basic questions of established importance. On the contrary, NASA appears to have begun with platform decisions and an emphasis on existing technology employed in highly expanded form. NASA's approach would have been eminently suitable to explicit engineering tasks like the Apollo and Manhattan Projects, where the underlying science existed to the extent that focussed aims could be addressed. However, EOS was not specifically an engineering program, and the underlying science was in a primitive state. The stated aim appeared to be to examine all aspects of the Earth System in the hope that both questions and answers would emerge from the massive flow of data. Such an approach can, under some circumstances, be justified. Indeed, much of what we currently know about the climate system has depended on serendipitous measurements taken for other reasons. Thus the Marshall Islands Nuclear Tests provided the meteorological data that led to much of our current understanding of tropical meteorology. This understanding permitted us to undertake the subsequent Atlantic Tropical Experiment of the Global Atmospheric Research Program in the 1970's. However, the Marshall Islands Tests had a compelling rationale independent of the resulting atmospheric science. We cannot say the same for EOS. From the beginning, EOS science teams were chosen to support instruments rather than to do science which would be assisted by the instruments. EOS provided no support for developing the basic science that might provide a foundation for the program. While it might be argued that such science was the appropriate object of NSF efforts, there was no provision for any coordinated utilization of basic science. Indeed, given the massiveness of the proposed program, it might be argued that it would be embarrassing to admit the relative absence of foundations, and, as a practical matter, EOS was too clumsy to be responsive in any case. The result has been an inability to rationally prioritize, and a vulnerability to radical restructuring and downsizing which seems to have had little impact on the science.

The situation became significantly more complicated as concern developed over global warming. The success of the environmental movement in popularizing this issue provided an after the fact rationale for what became known as MTPE, and an expansion of the effort to other agencies under the aegis of the USGCRP. This led in several ways to a defensive rather than a scientific approach. A major source of support was seen as depending on the perpetuation of an issue rather than on a focussed attempt to solve basic questions in a prioritized manner. Politicization contributed to this by establishing that agreement as to the possibility of crisis constituted public virtue, while scientific questioning was frowned upon (to put it mildly). The situation has been compounded by the desire of a variety of disciplines ranging from economics to trace gas chemistry to medicine to partake in the program. Such participation presupposes a well established problem, and leads to little interest in actually assessing this - especially among scientists whose interests are dependent on the existence of the basic problem. There is also the massive increase in university bureaucracy (nominally associated with the needs mandated by federal guidelines) whose needs are dependent on federal support, but whose immediate concern for science per se is limited.

The widespread insecurity within the scientific community following the end of the cold war also acts to distort normative scientific approaches. There is a conviction that funding is based on fear and would not survive the actual solution of the basic problems or the finding that some problems may not be as serious as supposed. The situation has persisted for so long that we now have a generation of scientists for which this situation seems normal. The political system seems to have had difficulty recognizing the importance of security and stability to the proper functioning of science. This contrasts strongly with the twenty year period following WW II, which, in many ways, constituted the golden age of American science. The issue is not simply one of scale. The level of support is far higher today than it was during the earlier period.

It must be emphasized that the role of observations is both to uncover phenomena, which must then be analyzed by means of theory, and to test the resulting theory with an explicit aim of falsifying rather than confirming the theory. In this crucial regard, scientific inquiry differs profoundly from legal advocacy – a frequently misunderstood point. With respect to MTPE, the aim must not simply be "better, faster, cheaper," but must be to place legitimate scientific inquiry at the center of the program. Fortunately, there need be no contradiction among these aims.

Having begun with a brief litany of structural problems, I must note that the ultimate spirit of science is still alive and well. Scientists still want to know how things work. They continue to ask questions, and huge amounts of data are available – even without additional programs. Indeed, it is a shortcoming of most new programs that they fail to give adequate attention to existing data. With respect to global change, the most obvious question is what is the gross sensitivity of the climate to increasing CO_2? It is curious how little attention has been paid to this basic quantity. Afterall, should it prove much smaller than what current models produce, then many of the remaining concerns over consequences of warming would prove less urgent.

In principle, this is an easy quantity to define. It is generally argued (though not without caveats) that doubling CO_2 would lead to an increased radiative forcing at the top of the atmosphere of 4 Watts per square meter. The question of sensitivity boils down to asking how much must the globally averaged surface temperature increase in order to get rid of this additional 4 Watts per square meter. This is what is being referred to when one says that one expects a doubling of CO_2 to lead to an equilibrium warming of from 1-5°C. Unfortunately, the expectation depends on weak aspects of current models where uncertainties are many times larger than 4 Watts per square meter. Currently, most assessments of models consist in model intercomparisons which is methodologically questionable. It would obviously be better to have actual measurements against which to test models. In principle this can be done. The global mean temperature fluctuates from year to year naturally. One can measure the top of the

atmosphere radiation budget in order to see how it changes in response to the observed changes in global mean temperature, thus yielding an observed value for the sensitivity. A preliminary attempt along these lines was made over a year ago by M.-D. Chou of NASA/Goddard, and he found a sensitiiivity that was about a tenth of what models suggested. However, the situation is not that simple. Chou used ERBE data and considered averages over only the tropical Pacific.

As I noted in a paper to appear in the Proceedings of the National Academy actual measurements of sensitivity would have to consider global means, and even then, the sensitivity will depend not only on the change in global mean temperature but also on its pattern. Nevertheless, I suggest that one should, at least, be able to obtain an upper bound on sensitivity. Moreover, one will inevitably get fundamental diagnostic quantities for testing models. With respect to the last item, C.Covey of DOE's Lawrence Livermore Laboratory has performed a preliminary comparison of model outputs with Chou's observations, and has confirmed the model tendency to overestimate sensitivity. At the moment, the main problem in going ahead with a better analysis is the absence of suitable data on surface emissivity over land. There is some possibility that data exists from which this may be extracted, but it is uncertain as to whether accuracy will be sufficient. In any event, there will be a small meeting in April at MIT where a few scientists from NASA, NOAA, DOE, JPL and various universities will gather to see what data is currently available to make such a study and to critically assess the proposed methodology. I am hopeful that the effort will succeed, but if it does not, we will know more exactly where we must improve our observations.

I should add that according to the work by Chou and by myself, the crucial factor in climate sensitivity seems to be the behavior of atmospheric water vapor (far and away the most important greenhouse gas, and completely natural) in dry cloud free regions where a 4% change in relative humidity leads to a change in the radiative flux of 4 Watts per square meter. Until very recently, our knowledge of the behavior of water vapor was severely restricted by the absence of reliable data; uncertainties and errors exceeded 20%. However, in the last two years a number of things have changed this situation significantly. The instruments used on meteorological balloons have improved as has their calibration algorithm. NASA is obtaining upper tropospheric humidities from SAGE II limb sounders, and the Department of Defense's 183 GHz microwave sounder on SSM/T-2 is allowing Roy Spencer and Dan Braswell at NASA/Marshall to prepare beautiful daily maps of water vapor over the whole earth. What we see is differing in important ways from what models are producing. A crucial aspect of the difference was identified by Sun and Held at NOAA's Geophysical Fluid Dynamics Laboratory where they found that the variations in water vapor at upper levels and at the surface were far more tightly coupled in models than they are in nature. This almost certainly points to numerical problems. Nevertheless, the same huge global programs which argue for the inclusion of ecologists, economists and physicians rarely point to the far more fundamental need for applied mathematicians to put the models on a sounder basis. Fortunately, this does not mean that mathematicians will not involve themselves; the problem is challenging enough to attract attention even without programs.

Turning to the second scientific item I mentioned at the beginning of my testimony, the fundamental problem here is to account for the major changes in climate that are known to have occurred in the past. Were such changes necessarily associated with changes in net radiative forcing, or are there basic mechanisms whereby such changes can occur independent of any net radiative forcing or of sensitivity to such forcing? In 1990, I published a paper in the Bulletin of the American Meteorological Society which pointed out that the atmosphere was very inhomogeneous with respect to its main greenhouse gas, water vapor, and that the earth's surface did not cool primarily via radiation but rather via evaporation and motion. The motions act to carry heat both poleward and upward where diminished water vapor permits heat to escape more readily via radiation. The obvious consequence of this is that if we do not accurately model the dynamic heat transport, we cannot calculate the mean temperature of the earth. No one in the atmospheric sciences would argue with this; it is absolutely basic. Rather,

members of the modelling community have argued that the models do well with such transports, and that there is no major problem here. However, extensive model intercomparisons conducted through DOE's AMIP program have shown wide differences among models and between models and observations. These differences also represent uncertainties and errors greatly in excess of the contributions from doubled CO_2.

A consequence of the mean temperature depending on dynamic transport is that there might be climate change in the absence of mean forcing. Motions depend on horizontal variations in heating rather than mean heating, and such variations occur for a variety of reasons ranging from ENSO events (dependent on the interaction of the atmosphere and the oceans) to variations in the earth's orbit. The motions responsible for carrying heat consist in a large scale circulation in the tropics, known as the Hadley Cell, and transient eddies in the extratropics. In a pair of papers in 1988 and 1992, A. Hou (of NASA/Goddard) and I established that changing positions and patterns of heating could greatly alter the intensity of the Hadley Cell; it was also noted that the Hadley Cell could be a major source for the extratropical eddies. Since then, W. Pan and I have established that orbital variations strongly modulate the Hadley Cell providing a possible link between orbital variations and ice ages. A. Hou and E. Chang at MIT have established that variations in Hadley intensity can alter polar temperatures, and Hou has dramatically confirmed this with NASA/Goddard analyzed data. The alteration of Hadley intensities by ENSO events has been established, and the relation of Hadley intensity to the intensity of extratropical planetary scale eddies has been observed by Hou as well as by Chen and van den Dool at NOAA. J.M. Wallace and his students at the University of Washington are finding that significant parts of observed global warming may, in fact, be associated with ENSO patterns. In a recent paper, I have shown that the mixing by extratropical eddies strongly conditions the response of the atmosphere to stationary forcing (as is provided by major elevations like the Himalayas and land-sea differences) which, in turn, determines storm paths. Strong evidence exists that existing models are failing to replicate this behavior, and efforts are beginning at NASA/Goddard to see how this can be remedied. P. Stone, at MIT, has quantified the failure of models to mix properly, and C. Giannitsis at MIT has developed a possible simple diagnostic by showing that mixing determines the position of a major circulation feature, the subtropical jet. In brief we now can be quite certain that the atmosphere (especially when coupled to the oceans) can undergo significant variations in mean climate even without external forcing. In ascertaining this, important possibilities have emerged for improving models for both climate and weather.

What can we conclude from the above. Although I have only focussed on two basic questions which I am intimately involved with, it is evident from these examples that significant advances in our understanding of Global Change are occurring with substantial, and generally unplanned, cooperation among a variety of scientists. It is equally clear that much of the progress is occurring quietly in areas that are not amenable to easy popularization. Most important, I hope to have demonstrated that the scientific community has the capacity to focus in prioritized manner on the basic science of Global Change regardless of whether the large planning bodies do so. The main contribution that the government can make to this science is to maintain the health and integrity of the scientific community – a task which is distinct, in many ways, from the maintenance of specific programs. A healthy scientific community can make progress even without major programs, though in some cases the resources required will benefit from larger efforts. Large programs without a healthy and creative community are almost certain to prove wasteful, and program planning from above by individuals not closely and personally involved in successful research is likely to miss those seemingly esoteric details that form the foundations of science. It can never be forgotten that instruments and programs do not answer questions; individual scientists do.

Chairman WALKER. Dr. Balling? And do I understand that you need the screen as well?

Dr. BALLING. That's correct, sir.

Chairman WALKER. Okay.

Dr. MACCRACKEN. And I will, too, sir.

Chairman WALKER. Okay. All right. Everybody needs the screen, so I'll put the screen down and leave it down this time.

STATEMENT OF DR. ROBERT BALLING, OFFICE OF CLIMATOLOGY, ARIZONA STATE UNIVERSITY, TEMPE, ARIZONA

Dr. BALLING. Well, thank you very much.

What we're looking at on the screen is the latest model run from the United Kingdom. The red line shows what happens to planetary temperature if we disturb the climate by only increasing carbon dioxide. The orange line represents what happens if we disturb the system by increasing carbon dioxide and sulfates. And the yellow line represents the thermometer network readings from around the planet.

When this was introduced in Berlin one year ago, it appeared that the climate debate was solved. It did seem that the model was replicating the climate system with some accuracy.

Those of us who have been skeptical on this issue I think were immediately charged with explaining to the world why the model now does replicate reality, and that's something we had in fact been rooting for for some time.

And I would argue today that that model run still leaves us with so many uncertainties, that it's not the least bit clear where we're headed to climatically.

This is a depiction I'm sure we'll see in a minute or two from Dr. Christy. It shows the satellite record which I believe is the most accurate record of planetary temperature available. It begins in January, 1979, extends to the present, or near present. And over the entire period of record, we do see that the satellite, looking at the low atmosphere, despite all the publicity, has shown statistically significant cooling.

If we then look at the past 20 years of the satellite records shown in blue, the thermometer records shown in yellow, and compare that with the model run from the United Kingdom, one could make something of an argument that the gap is actually widening.

Despite all of the publicity associated with a model run that replicates reality, reality in fact has been cooling and the model run that we see that apparently was going to replicate reality becomes even more distant from the satellite record.

There's no question that our scientific colleagues today are debating why the surface network shows this warming, but the satellite record appears to show this cooling.

We know that over the past 17 years, that the numerical model suggests we should have seen something on the order of 0.3 degrees per decade. We know that the thermometer network is something close to that.

And yet, if we look at the satellite date labelled MSU, or the radiosonde data which come from balloon launches around the world, we get cooling. And of course, this is a big part of the debate, why

these different data sets show different patterns that should be so clear.

Well, my geographic training also allows me to ask questions about where this warming should be located. Models throughout the world tell us that the bulk of the warming should be in the northern hemisphere, in the Arctic. Even a very simple model we run at Arizona State University makes this same prediction.

And so we can go look to see what's happening in the Arctic, and if we take that same satellite data from Spenser and Christy and look only at the Arctic, we again get statistically significant cooling.

I've stratified the data set by season. We're told that the winter season is the time when we should get the greatest warming. And yet, there is cooling in the winter season as well.

If we go back and look at the thermometer data that would be available for the Arctic for the past 50 years, we again see that there's absolutely no warming in the Arctic. This is quite troubling when this is the part of the planet where we think we should see the greatest amount of warming at the present time.

I've also been involved in determining trends in temperature at different locations around the planet. The bluest of the blues here would represent places where the temperature has cooled by over one degree Centigrade in the past 16 years.

And what you see is that the Hudson Bay area, which the models predict to have the greatest amount of warming, is in fact the place where the satellites see the greatest amount of cooling. And if we stratify the data by latitudinal bands, we really get nothing in the satellite system that looks consistent with what should be present given the model outputs.

Our group in Tempe has also been involved in a number of regional studies where we have looked at temperature records from the United States and from Europe and from South Africa and from Eastern Australia, and even the Middle East. And we do our best to gather the finest records we can, not contaminated from urban growth.

And in virtually every case, when we look at the model prediction versus reality, we continually find the lack of a linkage.

I would be the first to admit the models very poorly replicate climate patterns through time at regional scales. But once a scientist begins to pick one region after another, and continually finds little agreement between observed climate patterns and predicted patterns, you soon believe in the data and not so much in the model.

So my bottom line, I guess, is that no scientist would ever come here and say we need less data. In reality, here would be any number of data sets that could be constructed to help resolve this conflict between model predictions and observations.

Thank you very much.

[The prepared statement of Dr. Balling follows:]

Testimony Prepared for the U.S. House of Representatives Committee on Science

Hearing Date: March 6, 1996

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Introduction

In March, 1995, delegates in Berlin attending the First Conference of the Parties to the Framework Convention on Climate Change received a document showing the latest results from a numerical climate experiment conducted in the United Kingdom (Climate Prediction Group, 1994). One of the plots in that document showed the model output for global temperatures from 1860 to 2050 (see Figure 1). These results came from a numerical simulation that included both the warming effects of increasing greenhouse gases coupled with the cooling effects of sulfate aerosols. The plot also showed the actual planetary temperatures from 1860 to the near present as measured from thermometers around the world.

The scientists who prepared the report claimed that for the first time a climate model "has been able to replicate in broad terms the slow rise in global temperature since the middle of the last century." The obvious implication is that a model capable of simulating past conditions should be more reliable in its climate predictions for the future. By 2050, this model run shows a rise in global temperature of 1.5°C; warming in the Arctic exceeds 3°C, and a temperature increase in the United States over 1°C. The rate of warming is "probably twice the rate which some of the more sensitive ecosystems can tolerate."

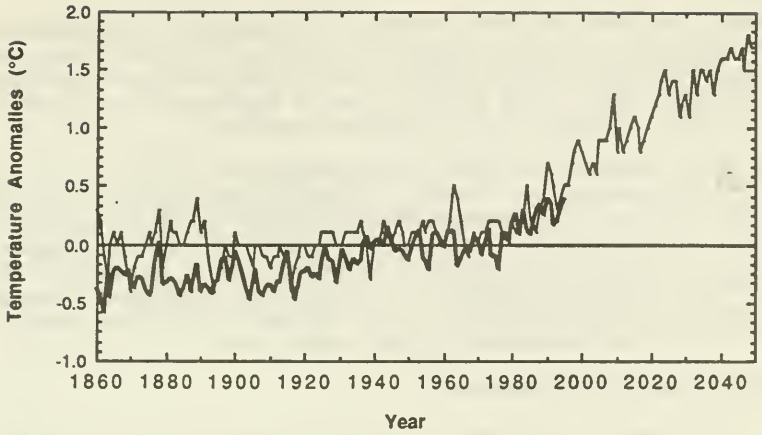

Figure 1. UKMO model run for increasing greenhouse gases and sulfate aerosols (thin line), and actual near-surface global temperature (thick line).

These same results have now appeared in major scientific journals (e.g., Mitchell et al., 1995), thereby furthering their impact on the greenhouse issue. However, many questions remain about the quality of all models, and the actual correspondence between the model output and the actual climate record is weak. Despite claims to the contrary, the models cannot simulate the observed temperature record with much accuracy; in fact, the gap may be widening.

Simulated Verses Observed Global Temperatures

Two different data sets are plotted in Figure 1. One time series represents the planetary temperatures that result from a combination of increasing emissions of greenhouse gases and sulfur dioxide. These calculations were made by a state-of-the-art numerical climate model at the Hadley Centre in Bracknell, England; the model includes detailed representations of the atmosphere, oceans, ice, and vegetation. The calculations required to produce these two time series took three months to run on one of the world's fastest supercomputers. The second time series in Figure 1 is made up of the actual near-surface global air temperatures determined from thermometers located throughout the world (Jones, 1994). Despite substantial efforts to avoid known problems, this temperature record is still affected by urban warming, measurement errors, instrument differences, and the lack of data from many remote areas, including the oceans.

In theory, the model run with greenhouse gas and sulfate perturbations should resemble the actual temperature record, and at first glance, the correspondence is fairly good. The agreement is particularly strengthened from the late 1970s to the present when an accelerated upward trend appears in both simulated and actual temperature levels.

To be more precise, the correlation coefficient between the simulated and observed temperatures over the entire 135-year period is 0.57; the model appears to explain 32 percent of the variance in global temperatures. However, a simple line with a slope of 0.05°C per decade has a correlation coefficient of 0.82 with the observed temperature data, and explains 67 percent of the variance in global near-surface air temperatures. A simple line explains more than twice as much variance in global temperature than the numerical climate model at the Hadley Centre.

Satellite-Based Global Temperatures

The further back in time we go, the less confidence we have in the estimation of global temperature. As we move toward the most recent decades, other data sets are available to represent global temperature. One data set is derived from satellite-based measurements of microwave emissions from molecular oxygen in the lower atmosphere. The data set is accurate to within a few hundredths of a degree, and the polar orbits of the satellites assure true global coverage (see Spencer and Christy, 1990).

The comparison of simulated temperatures, global near-surface temperatures from thermometers, and the satellite-based measurements is presented in Figure 2. The temperatures from the model and the satellite-based lower-tropospheric temperatures show no statistically significant relationship. The correlation between the two data sets is only 0.08; the satellite-derived data actually cool while the model predicts warming. One may argue that the satellites are measuring the lower 6 km of the atmosphere and the simulated temperatures are for the near-surface, but the models predict more warming in the lower-troposphere than they do for the surface. The actual gap between modeled and observed lower-tropospheric temperatures is greater than the gap implied in Figure 2.

Several papers have appeared in the literature challenging the accuracy and reliability of these satellite-based data (Hansen et al., 1995; Prabhakara et al., 1995). However, three facts show us that the satellite data are extremely accurate. First, satellite data are highly correlated with thermometer readings taken over the United States, Europe, and eastern Australia (e.g., Basist et al., 1995). The places in the world where we think we have the best near-surface air temperature data are in excellent agreement with the satellite data. There is no reason to believe that the satellite system suddenly loses its accuracy once it leaves the borders of these key test areas.

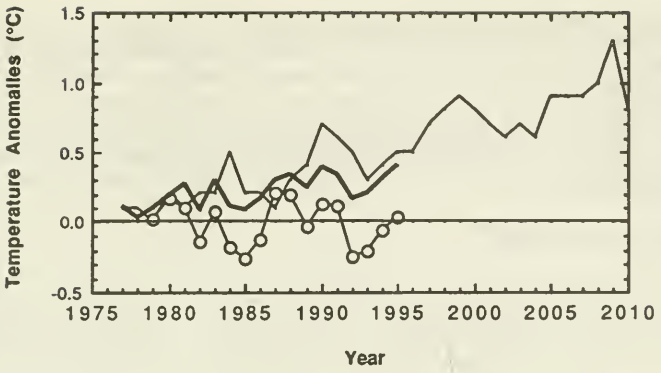

Figure 2. UKMO model run for increasing greenhouse gases and sulfate aerosols (thin line), near-surface global air temperature (thick line), and satellite-based lower-tropospheric temperatures (open circles).

A second data set also confirms the accuracy of the satellites. Twice each day, balloons are launched simultaneously throughout the world. In a highly coordinated effort, radiosondes relay back their measurements of temperatures, winds, and moisture at selected heights in the atmosphere. During the period of overlapping records (1979-present), the satellite data and the radiosonde data for the lower troposphere have a high correlation (+0.94) and they show nearly identical trends (both are -0.046°C decade^{-1}). An excellent review of the relation of these two data sets is presented by Christy (1995).

Another test of the quality of the satellite data involves determining planetary temperature fluctuations throughout the lunar cycle (Balling and Cerveny, 1995). During a full moon, the moon reflects and radiates a small, but not insignificant quantity of energy to the earth. During a new moon, no energy is reflected to the earth, and a trivial amount of energy is emitted toward the earth. A rather easy calculation will show that the earth should heat by a few hundredths of a degree during a full moon as compared to a new moon. Just as expected, the satellite-based temperatures warm by 0.02°C during a full moon over the temperatures experienced during a new moon. The precise determination the lunar impact on global temperatures is possible only if the satellites are extremely accurate in their measurements.

The satellite-based planetary temperature data are extremely accurate, and the satellite record does not show the warming signal that should be easily identifiable since 1979. Even when the potential effects of volcanism and El Niño/La Niña are taken into account, only a small warming of less than 0.1°C decade^{-1} can be determined from the satellite records (Christy and McNider, 1994). Furthermore, December 1995 and January 1996 have been cold according to the satellites, particularly given the lack of any major volcanic eruption.

Warming in the Arctic?

Another simple test exists for evaluating the performance of the latest numerical climate model results. All numerical model runs, including the latest ones from the Hadley Centre, predict greatest warming in the northern hemispheric Arctic region, particularly in winter. In the long run, the warm-up in the Arctic is due to melting snow and the exposure of darker soil surfaces below the snow pack. In the short run, the warming is due to the greenhouse enhancement of cold and dry Arctic air that is minimally impacted by the greenhouse effect of naturally-occurring water vapor.

However, the Arctic as a whole is not warming. The satellite record for the Arctic shows a statistically significant cooling of 0.28°C decade^{-1} since 1979. Kahl et al. (1993a, 1993b) showed that over the past four decades, no trend upward could be found in radiosonde measurements in the Arctic. The near-surface air temperatures of Jones (1994) show a slight, but not statistically significant, warming of 0.03°C decade^{-1} in the Arctic from 1948 to the present. There is no signal that remotely approaches the warming that should be apparent in the northern hemispheric Arctic area.

Conclusions

The recent results from the Hadley Centre are interesting, and they certainly represent steps in the right direction in estimating the climate future of the planet. Unlike so many numerical experiments in the past, the model is now being perturbed by the combined effects of greenhouse gases and sulfate aerosols. Also, model results are being compared directly to observed climate variations during the period of historical records. However, many discrepancies still exist when the model predictions are compared to historical data.

The Hadley Centre scientists are to be commended for their quality modeling efforts. These scientists know the strengths and weaknesses of both the design of the numerical model and its ability to replicate the climate of the past century. The more one compares the model outputs to the observed climate variations, the less agreement exists between the two. The Hadley Centre experiments may be fantastic achievements in applied atmospheric physics, computer science, and applied mathematics, but little

confidence should be placed in their climate prediction for the middle of the next century.

If the models are correct, we have a problem on our hands, and substantial changes in climate can be expected to occur in the coming decades. If we chose to believe in the near-surface global air temperature estimates, recent warming and record-breaking temperatures would support the low-end model predictions. Examination of the satellite-based global temperatures suggests that the atmosphere is not behaving according to the numerical climate models, and that the threat of global warming is relatively small. Regional climate patterns, particularly the lack of warming in the Arctic, also argue against the greenhouse threat. Continued combined efforts between the numerical modelers and the scientists dealing with historical records of climate will prove extremely useful in determining the fate of the climate system in the next century.

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Chairman WALKER. Thank you. Dr. MacCracken, you're next.

STATEMENT OF DR. MICHAEL MacCRACKEN, OFFICE OF THE U.S. GLOBAL CHANGE RESEARCH PROGRAM, WASHINGTON, DC.

Dr. MACCRACKEN. Thank you, Mr. Chairman.

My name is Michael MacCracken. I'm director of the interagency office of the U.S. Global Change Research Program.

As indicated in the biography in my testimony, I've been developing, testing and working with climate models for 30 years, and I'm proud to say I'm a climate-modeler, probably the only one up here given all the criticism that's going on. And I'm certainly willing to speak about the model results and comparisons to observations.

In this brief oral presentation, I want to make two basic points.

First, with respect to the program as a whole, it's a broadly-based program, as was said by Dr. Frieman earlier, looking at a full range of global environmental issues—seasonal to interannual variations, atmospheric chemistry, ecosystem change.

We're talking in this panel about one aspect of it, climate change, and actually, we're talking about the part of how the physical system will change and not how the ecosystems change and other things.

So that we have within the USGCRP a broad charter that comes from the legislation and what we are talking about today is a particular aspect of it.

The second point I want to make, and I'll expand on these both briefly, is that along with the vast majority of scientists that have been involved in this IPCC process, there's a strong indication that there's a discernible human influence on climate.

There are these apparent inconsistencies and uncertainties. That's how science advances, by identifying such things. But I do not believe that any of them fundamentally alter the consensus position of the IPCC that human activities are changing climate and will do much more so in the future.

Well, as I indicated, with respect to the program, there are four major areas—seasonal to interannual, where our goal is to improve predictions, which will be of great benefit to farmers for water resources and other purposes, to understand stratospheric ozone changes, which is vital for human health and how it affects the lower atmospheric chemistry, to understand changes in land cover and marine ecosystems. They supply many resources for society. It's important to understand those. And to understand how climate is changing, because people have to live within this climate as they work toward the future.

Now you're hearing a number of disagreements today and I want to say there are some things that I think we all agree on.

The first is that observations are critical to understanding the Earth system.

As indicated on the viewgraph, the EOS measurements they're taking are going to be absolutely vital for research in each of the four areas. So it's really important. The scientific community is starved for data. I am not worried about there not being enough investigators for that to happen.

It's important to understand that NASA is supplying data for the program as a whole, not just for the NASA scientists.

Well, we'll skip that one.

Let me say a second thing we agree on. We agree on that process-based research is important. We also agree that models are an important activity, I believe, for predicting the future. We certainly have to use empirical approaches, as has been discussed. But ultimately, we have to make sure that theory and empirical evidence agree.

We also have to understand the consequences of climate change and how they will be beneficial and detrimental, and how human systems will be affected by us.

Well, let me move to the second point just briefly.

We certainly want to have an open research program. We have an ongoing process of questioning. All of the research activities that we have have questions that they're trying to address. That's how science advances. It looks at conflicts of various kinds.

We have a very open process. We invite proposals. They're peer-reviewed. And that all goes on in an important, open way.

IPCC is the way we try and draw all of this together. The scientists do the best they can to try and come to some conclusions.

Science will always be contentious. That's the way scientists are. But we really believe we have a responsibility to all of you to try and deliver our best coherent answer as we can on a periodic basis, and it's for that reason that we highly commend the IPCC to you.

I want to emphasize that we focus on research. Dr. Michaels mentioned that something was going from being dangerous interference to moderate interference.

That is not a judgment that science makes or the research program makes. That's a judgment that has to be made in other ways by the policy community.

Now there are a few things I just want to say with respect to the comments that have been made.

The first is human climate change is discernible—if I can have the next one.

The human activities are dramatically modifying atmospheric composition and this is going to change the climate. There's no doubt about that.

The second, the next viewgraph shows data for the full year of 1995, how the surface temperature are changing, and it has indeed risen to, about, or even the warmest year that we have on record. This is also the warmest since about 1400.

The final point I will make is that sulfate aerosols do exert cooling in the southern hemisphere. Forcing and response are not in the same place, even though the aerosols are mostly in the northern hemisphere.

So I'm more than willing to address a number of these other issues in the questions, but in conclusion, let me just emphasize, it's a broad-based program, it's open for comments and participation.

We're passing on this world to our children and grandchildren and this is a very important issue to address.

Thank you, sir.

[The prepared statement and attachments of Dr. MacCracken follow:]

Prepared statement of

Michael C. MacCracken, Ph.D.
Director, Office of the U. S. Global Change Research Program

to the

U. S. House of Representatives
Committee on Science

Hearing on
U. S. Global Change Research Programs:
Data Collection and Scientific Priorities

March 6, 1996

Personal Background

Mr. Chairman, Members of the Committee, my name is Michael C. MacCracken and I have served as Director of the interagency Office of the U. S. Global Change Research Program since 1993. I am on assignment from the National Science Foundation (NSF), where I report to Dr. Robert Corell, Assistant Director for Geosciences, who is chairman of the interagency Subcommittee on Global Change Research that oversees the U. S. Global Change Research Program (USGCRP). I have in turn been on an assignment to the NSF since 1993 from the Lawrence Livermore National Laboratory (LLNL), where I was most recently the division leader for atmospheric and geophysical sciences and then of global climate research, working for more than 25 years on the development, testing and application of global climate system models. Prior to that, I was involved in modeling the climatic effects of greenhouse gases, of nuclear war, and of supersonic aircraft, in modeling the air quality of the San Francisco Bay Area (which led to a plan that has helped the Bay Area become one of the few regions in the country to meet the national oxidant air quality standard), and in leading interagency Department of Energy efforts on sulfate air pollution and massively parallel computing. A biographical statement is attached.

It is my pleasure to appear before the Committee to describe the interagency U. S. Global Change Research Program and its scientific priorities.

Program Organization

The USGCRP was established as a Presidential Initiative in the FY 1990 Budget, and was codified in the Global Change Research Act by Congress in 1990. The USGCRP is currently administered by the Subcommittee on Global Change Research (SGCR), which currently reports to the Committee on Environment and Natural Resources (CENR) of the National Science and Technology Council (NSTC). Within this scientific framework, the USGCRP oversees the scientific research concerning global change. I want to point out that the policy aspects of global change research are completely separate from the research effort and report through separate channels--*the USGCRP focuses on providing support for the fundamental inquiry and developing the underpinning scientific information concerning global change.*

The SGCR includes representatives of a dozen agencies and several Executive branch offices. The sizes of the contributions are closely matched to their specific interests and capabilities. Thus, NASA leads efforts relating to satellite observations of the Earth, NOAA

leads efforts relating to its interests in improving predictions of atmospheric and oceanic behavior for the benefit of society, the Department of Energy focuses on research relating to critical uncertainties involving projecting the effects of the emissions of carbon dioxide from combustion of fossil fuels for energy, NSF focuses on carrying out broadly based research to improve understanding of the Earth system, USDA focuses on the potential roles of and consequences for agriculture, food production, and forests, the National Institutes of Health (NIH) focuses on potential health-related impacts, DOI focuses on climate system history, water resources, and impacts on public lands, EPA focuses on impacts relating to ecosystems and societal impacts of global change, DoD focuses on prediction of seasonal climate anomalies affecting its national security operations, Department of Transportation (in a cooperative effort with NASA) participates in studies on the potential effects of aircraft on atmospheric ozone concentrations, the Smithsonian Institution focuses on global ecosystems, and the Department of State has responsibility for issues relating to international cooperation and assessments. While this may seem like a lot of agencies to be involved, global environmental issues are very complex and have many aspects. *Overcoming what might seem like barriers to cooperation among agencies is well worth the effort because of the wide range of challenges and the many interests and capabilities of each agency.* We very much need the best that each agency can offer, sometimes large and sometimes small, sometimes working closely on these issues and sometimes adding consideration to studies of related issues that are of even more importance to the agency. *Weakening or losing the participation of the various agencies would be detrimental to the overall program.*

USGCRP Program Goal

With so many agencies involved, it has been important to have an underlying scientific approach to investigating global change. The administration of President Bush presented the first scientific plan for the USGCRP in October 1990 and it has served as an important guide to research efforts over the past several years. We are currently in the process of preparing a new plan that is responsive to the advancing of scientific understanding and to the very helpful comments of the National Academy of Sciences in their review last summer.

Under the original plan, *the goal of the program has been to "establish the scientific basis for national and international policy-making relating to natural and human-induced changes in the global Earth system." The means for accomplishing this was to achieve a greater understanding of the Earth system "through the mutually reinforcing global change research activities of all nations and many organizations and programs ..."* The programs that have developed since this goal was established reflect its striving for a better predictive understanding of the world around us through a large measure of interagency, bilateral, and multilateral cooperation.

With the new plan, we have moved to make our goal statement more clear and better defined. Pending review this spring by the National Academy of Sciences and the broader scientific and stakeholder community, the proposed update to the USGCRP goal is:

- To observe and record what is happening to the Earth's environment,
- To understand why changes are occurring,
- To improve predictions of what is likely to happen,
- To evaluate the environmental and human consequences of change, and
- To develop capabilities for assessing the human health, and resource and economic implications of changes.

Scientific Approach

To meet the original goal for the USGCRP, the SGCR identified seven broad disciplinary areas of scientific uncertainty relating to global environmental change and within each area identified the highest priority areas for research. I have included a schematic showing these priorities as Figure 1. The seven areas, all of which have important elements, are:

- *Climate and Hydrologic Systems* (including especially research on clouds, oceans, water and energy fluxes, feedbacks, and interactions);
- *Biogeochemical Dynamics* (including especially research on fluxes and processing of trace species such as carbon, ocean biogeochemistry, cycling of nutrients and carbon in the biosphere, and terrestrial inputs to marine ecosystems);
- *Ecological Systems and Dynamics* (including especially research on the functioning of ecosystems, their response to stresses, interactions between biological and physical processes, and models of natural and resource systems);
- *Earth System History* (including especially work on past climates and ecosystems, the past composition of the atmosphere and circulation of the ocean, etc.);
- *Human Interactions* (including especially assembling information on the driving forces behind climate change, including population growth, energy demands, changes in land use, and industrial production and the impacts of climate change on people and nations);
- *Solid Earth Processes* (including especially those relating to coastlines, volcanic eruptions, permafrost, and other natural geological processes affecting the global environment); and
- *Solar Influences* (including especially monitoring of UV radiation from ozone depletion, the response of the atmosphere to solar variations, monitoring current variations in solar radiation, and establishing the historical record of changes in solar radiation).

Within this broad framework priorities were established leading to greater resources in the most important areas. Research, however, was sustained across each of these broad areas so as to encourage scientific exploration and investigation and so as not to submerge or prematurely dismiss uncertainties. For most of these areas, the program provided for both coordinated programs that involved scientists working together (which can really help to improve overall understanding of a process) and support for individual investigators (who are effective at identifying new areas and uncovering weaknesses)--both types of activity are essential to a vigorous scientific program.

Like all major research activities, the USGCRP requires a range of approaches for accomplishing its goal. The original USGCRP plan can be grouped the activities into the following categories:

- Documentation of Earth System change through observational programs and use of data management systems;
- Focused studies on controlling processes and improved understanding; and
- Integrated conceptual and predictive models.

These efforts remain clearly identified in today's programs and closely match the first three elements in the new program goal statement. To better be able to provide estimates of the potential importance to our nation and the world of global environmental change, we are currently striving to build-up research in two additional areas, namely:

- Environmental and human consequences of change, and
- Assessment of the health, resource, and economic implications of changes.

In addition, to evaluate and synthesize all of the relevant information in a useful way, the USGCRP participates in international scientific assessments that evaluate, synthesize, and integrate scientific understanding for consideration by decisionmakers.

Research in each of these areas is vital to providing the necessary information base for decision makers:

Observations and Data Management: In the area of observations and data management, the largest activity is the NASA Earth Observing System (EOS) program, which will be covered by others in testimony today. From a research perspective, it is vital to have a wide range of observations to have any hope of understanding what is happening. While some suggest that we should just start measuring a specific parameter when we know it is needed to address a particular scientific question, this is not the way in which to gain timely information about long-term changes. For this challenge, we will surely need to have a wide range of information over extended periods--waiting would only delay having any data and preclude the possibility of fortuitous discovery that is likely from having a diverse and broad observational capability. In addition, developing and deploying new instruments takes time (so waiting until all questions are completely formulated to get started also causes delays). It is generally agreed that what we need now is many more observations than we have--leading to proposals for Global Observing Systems for the atmosphere, the oceans, and the land surface. *NASA's EOS will be a very important contribution to global observing, both because of what it will observe and because it is spurring other nations to make many commitments so that the world community will have an invaluable scientific data base (see Figure 2).*

While EOS is the most expensive of the observation programs, there are others. *We rely especially on the observations taken by NOAA and many other agencies for other related purposes* (e.g. weather forecasting). Similarly, while the NASA EOS program has the need for the largest new data base management system (EOSDIS) and is using it now to make available results from existing and past satellites, other agencies have joined together with NASA under the USGCRP auspices to create a common access system known as the Global Change Data and Information System (GCDIS).This system and the "full and open" data policy of the United States have provided information for projects and investigators in a way that has stimulated both progress and the close examination of the understanding being pursued by my fellow witnesses. In FY-95, the USGCRP devoted about 60% of its budget to observations and data management because, once time passes and an observation is missed, the potential to observe is basically lost forever. For example, had we not been observing when the Mt. Pinatubo eruption went off, we would have missed a really unique event to use in testing our understanding and our models--waiting simply misses opportunities!

Process Studies: Knowing what is happening is the first step to being able to project future conditions; understanding why is the second step. The way in which we do this is to determine how each process influencing the Earth system works; how clouds transmit and absorb radiation, what controls the amount of water vapor in the atmosphere, how the ocean takes up carbon dioxide and heat, what might cause the glaciers to melt or accumulate ice, and so on. Here, *the U. S. has joined with other nations in the World Climate Research Programme (WCRP), the International Geosphere-Biosphere Programme (IGBP), and the International Human Dimensions Programme (IHDP) to consider and carefully plan coordinated and efficient research programs.* Together with some additional national research programs (e.g., concerning our forests and ecosystems), these international programmes provide an organizing framework for cooperative multilateral efforts in each of the seven disciplinary areas listed above. In all of these studies, scientific questions are carefully posed, and a

research plan is developed and reviewed for consideration of funding by nations and agencies.

Because it is so important for scientists to understand with high confidence why something is happening before making projections, the USGCRP devoted about 30% of its FY-95 budget to process studies. [This issue of the level of confidence scientists are seeking is discussed further below under assessments.]

Integrative Conceptual and Predictive Modeling: For simple systems or single processes, conceptual (or mental) models can be particularly useful. For systems as complex as the full Earth system, arguably the most complex of all research endeavors, a systematic means must be found for incorporating our understanding into a quantitative framework. *The approach that is used is to construct mathematical models that to the greatest extent possible rely on fundamental and immutable laws of nature.* Reliance must be placed on various approximations because understanding will never be fully complete and computer size and resources are limited. Uncertainties will always exist—and there will always be questions for not everything can be explained; but uncertainties are also the reason for an aggressive associated program of observations, analysis, and process studies.

The mathematical climate models (variously called climate models, general circulation models, or Earth system models depending somewhat on their implementation) strive to include all that is understood about the climate system. Because there is no means to prove them right--only to see where they break down--the models are constantly being put through an increasingly grueling series of tests to see how well or poorly they match observations. Models reproduce many aspects of the observed climate. That there are shortcomings, however, is to be expected--all modelers acknowledge them (just as all good observationalists acknowledge the shortcomings in their observations). The challenge is identify why they are not precisely reproducing nature and how to make them better. But at any given time, *models are at the cutting edge of what we understand.* They treat dozens of processes spread out over the globe and up through the atmosphere and down through the oceans, all the time requiring that everything be done consistently--no leaving out a process here and including it there, no assuming that changing one thing will not change something else, and so on. While experiences from past climatic conditions can be a rich source of tests of models (hence we study paleoclimates), only models can provide quantitative projections of future conditions. [As an indication of the need to rely on computers to do the calculations, Lewis Richardson in 1917 did by hand all the calculations that a computer now does in order to predict the weather. Using a relatively simplified set of equations, he spent roughly a year of his life calculating the changes in one hour's weather over Europe -- all of the citizens of the U. S. doing hand calculations could not come close to keeping up with present models that rely on advanced supercomputers.]

While it might be tempting to wait until each process is understood before model calculations are attempted, making and analyzing such calculations is as much part of the research and learning process as are observational and process studies. All of these efforts must proceed in parallel. In support of modeling activities, the USGCRP devoted about 5% of its overall budget in FY-95.

Environmental and Human Consequences: In that we seem to readily survive changes in the seasons from winter to summer and back and moving from Buffalo to Phoenix, it is sometimes hard to understand the importance of what may seem like small changes. However, the types of changes that are being projected generally create conditions that perturb natural conditions to new average levels that are generally beyond what has been experienced for thousands to tens of millions of years--times well before the establishment of human communities. Thus, increasing summertime temperatures in the Midwest by

several degrees could well require adjustments in cropping, planting, and irrigation (some of which might provide opportunities for increased productivity once adjustments are made); rising temperatures in mountain regions in winter could accelerate snowmelt and runoff, requiring changes in water resource systems; shifts in the freezing line could extend the potential reach of warm weather disease vectors if we are not persistent in support of public and community health practices; rising sea levels could threaten coastal regions, especially when strong storms create very high tidal surges; and shifting patterns of temperature and precipitation could lead to die-offs and other changes in forests and grass lands as natural species shift and reestablish themselves elsewhere.

Some of these changes are subtle, most are poorly understood, and the potential for surprises is high. As estimates of potential changes in the global environment have improved, it is becoming increasingly helpful to look closely at the potential consequences of changes for the environment and for human activities and natural resources. The USGCRP devoted about 3% of its FY-95 budget to these activities.

Health and Resource Implications: Having projections of how climate will change and estimates of how these changes will affect particular natural resources, developing an understanding of the importance of the changes for society--for you and me--requires that an integrated consideration of all of the effects, of their economic and social importance, how adjustments and adaptation might take place, and of what options exist and technologies might emerge, all in the face of population growth and the evolution of societies. Providing precise predictions is, of course, impossible--human and natural events are simply too uncertain. However, by looking at past experiences and trends and by making some assumptions about what might happen, we can explore how environmental changes may impede or amplify particular trends or situations, what costs might arise and what approaches might reduce costs or even provide multiple benefits. Research in this area thus needs to focus on methods for weighing impacts of different types, how human health might be affected and represented, how market forces can accelerate or impedemovements toward new and more efficient technologies, and much more.

The USGCRP devoted about 2% of its overall budget in FY-95 to developing better techniques for evaluating the economic and societal significance of global environmental change and examining the health consequences of global environmental change.

Scientific Assessments: In pursuing this wide range of research efforts involving multiple environmental stresses, multiple investigators are supported and a wide solicitation of viewpoints is sought to ensure that the full range of hypotheses is being tested. Science progresses by focusing attention on areas where there are disagreements and then developing research programs that can bring understanding. Criticism and thoughtful disagreement are normal parts of the scientific process, and when it has not been so, progress has been slow indeed. Thus, questioning, criticism, and uncertainties must always be at the forefront of scientific discussions. The USGCRP promotes open-minded, constructive, suggestive, and participate criticism and questioning. While science may thus seem disputative and contentious to those seeking guidance for deliberative decision-making, it is just what makes science exciting and effective for addressing complex issues.

There is, however, at any given time a scientific responsibility to always provide for decision makers and the public the best possible representation of scientific thinking on critical issues facing humanity. To accomplish this, discussions among scientists and decision makers have identified broadly based scientific assessments as being the best mode of communication between the two sides. Such assessments are designed to describe what is known, what is uncertain, what is not known about how the environment is likely to change (due to both natural and human influences), how such changes will affect resource systems of importance

to society (e.g., food production, water resources, public health, forests and ecosystems, coastal communities, etc.), and what the economic and social impacts of the changes and of various alternative approaches may be. The process of developing such assessments must be open, must be encompassing, must be independent, and must be carefully scrutinized.

To meet this very important challenge, the U. S. participates actively in international assessments on ozone depletion, climate change, and biodiversity and undertakes national assessments on issues such as the effects of aircraft on atmospheric chemistry. We strongly commend to your attention the several assessments that have been prepared in recent years--they represent the carefully considered views of a wide array of scientists, having had input from many, many scientists and having been reviewed by other scientists, scientific program leaders in various nations, and by non-governmental organizations of many types and perspectives.

Enhancing the USGCRP Focus on Areas of Most Scientific and Practical Importance

Since the start of the USGCRP, the focus of the research efforts hasencompassed a range of environmental issues. These have included depletion of stratospheric ozone, the potential for the global climate to change, natural variations of the climate over seasons and years, and the general state of the world's ecosystems in the face of deforestation and desertification. While commending the USGCRP for the quality of the disciplinary research in the areas outlined earlier (and strongly supportive of its continuation), the review of the USGCRP by the National Academy of Sciences (NAS) in the summer of 1995 (as well as an emerging sense from within the agencies participating on the Subcommittee for Global Change Research--SGCR) recommended that, in order to be most effective, the USGCRP "should focus on priority issues in four mature areas of Earth system science that are of great scientific and practical importance."

The SGCR is moving aggressively to implement the NAS recommendation. The four environmental issue areas (which are slightly renamed from the those suggested by the NAS) and their highest research priorities are:

1. Seasonal to Interannual Climate Variability

The climate of the Earth continually experiences natural variations on seasonal to interannual time scales, as evidenced by the El Nino cycle. These naturally occurring fluctuations can lead to extreme climate events such as droughts, heat waves, and floods. Extended periods of drought and heat can increase the susceptibility of urban settlements and forest lands to fire, can disrupt food production and water supplies, and in developing regions, can occasionally lead to massive human migrations. Prolonged and excessive periods of precipitation can cause flooding, delay planting, contaminate water resources, and temporarily disrupt patterns of production and trade.

An improved ability to document and then forecast trends and patterns of change in ocean temperature, snow cover, sea ice, and other factors that contribute to changes in the global climate over seasonal to interannual scales could lead to a reduction of adverse impacts from potentially destructive climate events. Early warnings enable communities to develop strategies to better prepare for these events by, for example, implementing revised planting schedules, switching crops, and modifying water management, all of which have been demonstrated to lead to reduced costs and impacts.

Observations and analyses indicate that in some regions of the globe, seasonal to interannual variations of atmospheric conditions can be predicted up to two years in advance. These predictions are based on observed variations in parameters such as sea

surface temperature, soil moisture, and snow and sea-ice cover. Significant changes in seasonal to interannual climate may be a key to the detection of longer-term climate changes.

Science Goals for Research on Seasonal to Interannual Climate Variability

- Observe and document the trends and patterns of changes in ocean temperature and circulation, ocean/atmosphere interactions, snow cover, sea ice, vegetation, and other factors that contribute to climate anomalies and related extreme events such as droughts, floods, and heat waves.
- Understand the controlling processes relevant to climate on seasonal to interannual time scales and regional to global scales, and develop predictive climate models that represent these processes.
- Forecast seasonal to interannual climate fluctuations and associated extreme events and simulate the potential economic impacts on agriculture, water resource, and other socio-economic systems.

3. Climate Change Over Decades to Centuries

Human society is highly dependent on the Earth's climate. Climate patterns and human adaptations determine the availability of food, fresh water, and other resources for sustaining life. The social and economic characteristics of society have also been shaped largely by adapting to the seasonal and year-to-year (interannual) patterns of temperature and rainfall. While anomalous variations in these shorter time scale patterns can have serious effects on society, the vulnerability of society to longer-term climate change, occurring over periods of decades to centuries, will depend on its ability to understand and respond to this change. Thus, it is imperative that society develop the strongest possible scientific understanding of the causes and dynamics of climate change and greenhouse warming, the potential ecological and socioeconomic impacts of change, and the implications of alternative courses of action to mitigate and adapt to change.

Scientists have determined that climate can be influenced by both natural forces and human activities. For example, habitable temperatures are maintained on Earth by a natural phenomenon known as the "greenhouse effect." Solar radiation is absorbed by the Earth's atmosphere and land and water bodies. The resultant heat is re-emitted as long-wave radiation, some of which escapes to space and some of which is absorbed and trapped by atmospheric gases such as water vapor, carbon dioxide, methane, nitrous oxide, chlorofluorocarbons and ozone. While some of these gases are present naturally, increased concentrations of greenhouse gases as a result of human activity can enhance this natural greenhouse effect, creating additional warmings of the surface and the atmosphere. Human activities such as fossil fuel combustion and land-use change have resulted in a 30% increase in atmospheric carbon dioxide and have contributed to more than a doubling of the methane concentration since preindustrial times.

Human-induced and natural changes in global land cover (such as deforestation and desertification) and emissions of aerosols (from fossil fuel burning and volcanic eruptions) also influence climate. Although much has been learned, there are still significant improvements to be made in estimating how human activities will combine with natural influences to affect the future global climate.

IPCC assessments conducted with the participation of thousands of scientists from more than 150 countries and with significant USGCRP participation, suggest that emissions of greenhouse gases and sulfate aerosols could, by end of the next century, lead to an increase in global mean temperatures of 0.8 to 3.5°C (about 1.5 to 6°F), a rise in sea level of 15 to 95 cm (about 6 to 38 inches), and a global change in precipitation patterns. Among other uncertainties, the magnitude and location of projected shifts in global precipitation patterns remain particularly difficult to predict.

Observational data show an increase in global average temperature of about 0.5°C (about 1°F) over the last 100 years. The likelihood that this warming is due primarily to natural variability is low. This observed warming trend is continuing despite the influence of the Mt. Pinatubo volcanic eruption, which caused volcanic emissions to reduce incoming solar radiation for nearly two years. The most recent climate model simulations have been able to explain the magnitude and temporal pattern of this observed trend reasonably well. To build greater confidence in predictions of future climate, further improvements are needed in modeling the influence of atmospheric aerosol concentrations, the cycling of atmospheric water in all its phases, cloud-radiation interactions, ocean-atmosphere coupling, and in predicting the expected range of natural climate variability.

Projected climate change over the next few decades, including changes in temperature, precipitation, and sea level, can add to other stresses on natural systems caused by other factors such as population growth, land-use changes, and pollution, posing risks to managed and unmanaged resource systems. Although temperature changes of the magnitude expected from the enhanced greenhouse effect have occurred in the distant past, the evidence suggests that the changes generally took place over centuries or millennia instead of decades. Because rates of natural migration and adaptation of species and communities appear to be much slower than may be forced by the predicted rate of climate change, populations of many species and inhabited ranges could decrease as the climate to which they are adapted effectively shifts northward or to higher elevations.

Overall, various strategies for coping with climate change can be identified for "intensively managed" systems (such as agriculture, water resources, and developed coastlines). For these systems, technological and management options exist to some extent today, although they may be costly to implement. By comparison, fewer options have been identified for natural systems such as wetlands and wilderness areas.

Changes in climate may also have significant impacts on human health. These impacts may include increases in mortality and morbidity as a result of a higher frequency of heat waves and synergistic effects from higher temperatures and air pollutant mixtures (higher temperatures may cause changes in urban air chemistry). There is also evidence that a changing climate will cause a migration into higher latitudes and altitudes of some diseases, such as malaria and dengue, the incidence of which is highly correlated with rainfall and elevated nighttime temperatures.

Science Goals for Research on Climate Change Decades to Centuries

- Observe and document the trends and patterns of change in the Earth's climate system, including the atmosphere, oceans, glaciers, sea ice, and the biosphere.
- Understand Earth system processes relevant to the regulation and radiative forcing of climate, and develop predictive models of regional to global climate change over time scales from a decade to a century.
- Assess the vulnerability of Earth systems, including economic, human health, and ecological systems, to the predicted rates and magnitudes of climate change.
- Support national and international science and technology assessments of the climate system that bring research results from natural and social sciences into a framework for evaluating and communicating the likelihood of significant climate change, and society's potential for mitigating, adapting, or responding to change.

3. Changes in Ozone, UV Radiation, and Atmospheric Chemistry

Life at the surface of the Earth is protected from harmful ultra-violet (UV) radiation of the Sun by the stratospheric ozone layer. Over the last several decades, synthetic chemical compounds, such as chlorofluorocarbons (CFCs) and halons, were developed to provide a new generation of refrigerants, insulating foams, fire retardants, and other products. Unfortunately, after extensive use of these compounds, it was discovered that

they remain inert in the atmosphere until they reach the stratosphere, where they break down into an active form that destroys ozone. One chlorine atom originating from a CFC molecule can destroy thousands of protective ozone molecules.

Satellite and ground-based observations confirm that losses of ozone are occurring seasonally, particularly in the springtime polar vortex of the Antarctic stratosphere, leading to what is known as the ozone "hole." Also of concern is the more moderate ozone depletion observed in mid-latitudes, where a large portion of the Earth's population resides. In the absence of changes in clouds or pollution, decreases in atmospheric ozone will increase ground-level UV radiation.

Analyses of data related to human health, Antarctic marine phytoplankton production, and careful field and laboratory experiments on the impacts of elevated UV exposure, indicate that increased UV radiation at the surface could have substantial negative impacts on human health, fish populations, and many terrestrial and marine ecosystems. In humans and other animals, impacts include immune system suppression, increased incidence of serious sunburn, cataracts and epidermal lesions, reduced vitamin D synthesis, and cancer. In plants, exposure to enhanced UV radiation can inhibit the essential process of photosynthesis. Increased UV radiation can also influence agricultural productivity and cause deterioration of synthetic materials such as plastics.

Due to global recognition of the implications of ozone depletion, emissions of many CFCs and halons are to be phased out over the next few years. Global observations of CFC concentrations in the atmosphere indicate that actions taken in response to the Montreal Protocol and its amendments are having the desired effect. Atmospheric measurements of trichloroethane, a short-lived ozone-depleting substance, indicate that its concentrations are actually declining.

With the significant advances over the past decade in understanding stratospheric chemistry, the next ten years will see a particularly strong focus on understanding the even more complex chemistry of the lower atmosphere. The lowest portion of the Earth's atmosphere, the troposphere, is intimately involved in the chemistry of global change. Natural tropospheric processes cleanse the atmosphere of most pollutants, thereby interrupting the throughput of many ozone depleting substances to the stratosphere, and limiting the persistence in the atmosphere of the most common greenhouse gases. Accordingly, gaining a predictive understanding of tropospheric chemistry is central to quantifying how the troposphere works both to protect the stratospheric ozone layer and to determining the climatic impacts of aerosols and greenhouse gases which arise from surface pollution. Research will focus on field campaigns designed to elucidate the chemical and mixing processes that control trace substances in the lower atmosphere, on space-based observations to achieve global coverage, and on modeling studies to test and refine theories underlying prognostic capabilities.

Science Goals for Research on Changes in Ozone, UV Radiation, and Atmospheric Chemistry

- Observe and document the trends and patterns of change in ozone concentrations in the Earth's stratosphere and upper troposphere and the related trends and patterns of UV radiation at the Earth's surface.
- Model the physical and chemical processes of the stratosphere and upper troposphere that will allow predictions of ozone change and the resulting change in UV radiation at the Earth's surface.
- Assess the implications of changing ozone concentrations and the resulting changes in UV radiation at the Earth's surface to human health and other life forms.
- Assess the efficacy of the development of new replacement compounds for chlorinated and brominated compounds.
- Develop a predictive understanding of the chemistry of the global troposphere

4. Changes in Land Cover and in Terrestrial and Marine Ecosystems

Human-induced changes in land cover have occurred throughout human history. Large tracts of land have been cleared for agriculture, forestry, the collection of fuelwood, and for urban and industrial growth. Ecosystems have been transformed both in response to land-cover change and as the result of the inadvertent and intentional introduction of plants and animals from outside their normal habitats, thereby introducing new pests, diseases, and competitive species. The damming, diversion, and rechanneling of rivers, the development of intensive agricultural irrigation systems, and the dramatic increases in the consumption of water for urban and industrial purposes have altered the natural water cycles of many regions, the impacts of which were often felt in remote locales because of the far-reaching character of hydrologic systems.

Worldwide land-cover and ecosystem changes have become especially pronounced in recent decades. As the rate of change in many places have accelerated, so also have the magnitude of those changes and their impacts. More than ever, a comprehensive view of land-cover and ecosystem change is needed. Fortunately, new techniques for acquiring and managing information about these elements have been developed. The science and new technologies for measuring and understanding the dynamics and consequences of land-use and land-cover change have improved dramatically in the last decade. Studies in both tropical and temperature regions using Landsat data have demonstrated that rates of deforestation can be documented, and regrowth and reclearing of secondary growth also can be measured. Satellite data can be combined with ground-based and airborne measurements to determine the influence of land-cover change on biological diversity, hydrologic processes, and the potential for future resource production and utilization of an area. Research results and methods for measuring large-area land-cover and land-use change are now being used by commercial interests to develop sustainable plans for the production of livestock and forest products and to manage public lands for multiple uses.

The increasing volume of data on land cover and related variables greatly facilitates analyses of the dynamics of land-cover change. USGCRP-sponsored research has examined the patterns and rates of land-cover change in a wide range of different areas, exploring different ways for classifying land cover and related land-use practices. These efforts have led to delineation of a set of land-cover regions for the globe. Regional case studies have begun in many of these regions using a common protocol developed by scientists involved in the Land-Use and Land-Cover Change (LUCC) project, a core project of both the International Geosphere-Biosphere Programme (IGBP) and the international Human Dimensions of Global Environmental change Programme (HDP). Through the use of comparable approaches in the conduct of these regional case studies, analyses of the dynamics of land-cover change in each of the regions form the basis for more general advances in understanding the complex interactions among human and natural processes. In the next decade, major new advances in the capabilities for remote sensing of land-cover and land-use dynamics are expected, resulting in an even greater increase in data available for documenting the dynamics of land-cover change.

In addition to gaining a better understanding of changes associated with the land, change affecting or affected by the oceans (which cover 70% of the Earth's surface) are also critical to understanding the dynamics of the total Earth system. Warmed by the Sun and driven by winds, this vast mass of flowing water regulates the planet's seasonal and interannual climate fluctuations. The oceans are home to diverse communities of plants and animals, which take in and release dissolved carbon, nitrogen, oxygen, and other elements. Marine organisms participate in the global cycles of such elements, affecting their concentrations in the oceans, atmosphere, and land. Studies of ocean biology and circulation are crucial to understanding these biochemical cycles and their role in the maintenance of life.

The oceans now are under increasing pressure from human activities. Industrial waste, synthetic fertilizers, and other pollutants are carried by rivers into the ocean, where they can injure life and cause radical changes in the composition of marine ecosystems. The species composition of algal blooms is shifting, and "red tides" of toxic algae are more common along the coasts of the world. Coral reefs, which support a wide variety of organisms in the tropical seas, have been particularly hard hit. Fish and shellfish have suffered as well, with heavy impacts on marine industries. Through significant new remote sensing capabilities and the use of other satellites, aircraft, and ground-based instruments on ships, buoys, and moorings, USGCRP-sponsored research is studying the responses of marine life to various kinds of natural and human-induced global environmental change.

Humans are placing increasing demands on terrestrial and marine ecosystems. The challenge is to understand the potential consequences of natural and human-induced transformations and the effects of industrial activity on the structure and function of terrestrial and marine and coastal ecosystems. Such understanding is essential to maintaining the goods and services essential for human life provided by ecological systems and for developing mitigation options. It is also essential that the potential benefits derived from human-induced land transformations and industrial processes be balanced against the potential costs associated with the reduction or loss of ecological goods and services which result from such activities.

Science Goals for Research on Changes in Land Cover and Terrestrial and Marine Ecosystems

- Observe and document the trends and geographic and temporal patterns of change in global land cover.
- Understand the processes, both natural and human-induced, that lead to changes in land cover, land use, and ecosystem health, including those resulting in deforestation, desertification, and loss of global resources, such as biological diversity and reductions in productivity of farms and fisheries.
- Predict the likelihood of significant changes in the extent, vitality, and diversity of global resource systems in relation to local, regional, and global economic development.
- Understand the processes that regulate ocean uptake of atmospheric carbon dioxide.
- Predict changes in the structure of phytoplankton (microscopic plants) communities—which form the base of the food chain in the ocean—and understand their links with higher species (e.g., fish, invertebrates, marine mammals).

Revisiting Critical Scientific Priorities Concerning Climate Change over Decades to Centuries

The charter for this hearing indicates a special interest in the scientific priorities concerning climate change research. As part of our periodic planning effort, the USGCRP is presently renewing its program structure in response to the helpful comments coming from the National Academy of Sciences review of last summer. As I indicated above, this is only one of our several research areas, each of which is going through a similar redefining effort and review by various National Academy committees and panels. For each we are updating our overall research plan.

The updated objective of our climate change research is to more reliably predict the changes in climate and the global environment that will occur over decades to centuries as a result of the continuing and projected changes in population, energy use, and other factors. In support of this objective, we are proposing six sub-objectives:

1. Quantify the natural and human-induced factors that change atmospheric composition and radiation;
2. Characterize natural climate variability and the factors that contribute to decadal and longer-period fluctuations.
3. Improve quantitative representations of climate system mechanisms and feedbacks;
4. Improve predictions of the climate change and identify the human-induced component in the recent climatic record;
5. Estimate the near- and long-term consequences of climate change and natural variability for the environment and societal resources (e.g., agriculture, water resources, etc.); and
6. Conduct comprehensive assessments that summarize scientific understanding and the socio-economic consequences and implications of global climate change and natural variability.

For each of these subobjectives, we in turn are identifying critical areas of uncertainty where research is essential. As just a sampling, these include cloud-water vapor-radiation interactions, the climatic effects of aerosols, natural variability, tropospheric chemistry, ocean circulation heat uptake and the potential for sudden change, ocean-atmosphere interactions, regional estimates of climate change, sea level change, global climate models, consequences for forests and food production, water resources, marine and coastal ecosystems, economic influences of climate change, consideration of non-market impacts, integrated assessments, and more. To really improve our projections of future changes, we need an integrated and broad-based research effort--given the importance of the issues involved, we need to strive to learn even more while at the same time recognizing that the prospects for significant climate change are very real.

Comments on a Selection of Scientific Statements about Global Climate Change

As part of the on-going scientific process of questioning and critiquing, with everyone checking each others results, it is quite natural that, in addition to there being areas for which there is strong agreement, seeming inconsistencies will be identified and areas will be found where the explanation of scientific findings can be improved. The USGCRP is very open to this process, and, in fact, its many research programs are all focused around questions and uncertainties. We prioritize our program around addressing those questions that are most important and where progress is most needed.

In the recent IPCC assessments, an interesting revelation has been the difference in confidence levels that are expected and are justified by the present state of knowledge. For IPCC WG I on the expected changes in climate (and a similar perspective applies for the ozone assessment), traditional scientific analyses are seeking high levels of certainty (e.g., 90-95%) before drawing conclusions and the results are given with uncertainty bounds. For WG II on the impacts of climate change, levels of certainty tend to be lower, but still significant, and again ranges of impacts are suggested. For WG III on economic implications of change, only rough central estimates that are acknowledged to be incomplete are available. What is most surprising about some of the statements about today's hearing and the public discussion of uncertainties is that the discussion tends to focus on the results that are most certain in the IPCC findings, findings for which mainstream scientists are arguing about whether the odds of their central predictions are 5 to 1, 10 to 1 or even 20 to 1. While by no means all aspects of the climatic effects can be estimated with such certainty, such levels are well above those for which many societal decisions are made.

It is not the right to question these findings that is at issue in any of the debates and discussions that we are having. What is at issue is the best way for that process to proceed

while at the same time developing a consensus view on the best scientific statements of what is known, unknown and uncertain. The community of scientists largely believes that the best way is to periodically conduct open, international, scientific assessments that provide the opportunity for all to participate and to make their cases to their fellow scientists and the broader community. We believe that the IPCC process largely meets that challenge, representing the central consensus of the world scientific community. *It is for this reason that we so strongly urge the wide consideration of this report as the authoritative base for scientific findings on global climate change.* There will always be critics and those not fully satisfied, and indeed there are both those who believe the conclusions should be weaker and those who believe the conclusions should be stronger. However, at this time, the IPCC results are the most thoroughly reviewed and considered views on global climate change and they deserve very high respect.

The very great importance of this issue for society in terms of the threat of environmental change and the potential for changing aspects of important societal activities has generated considerable public discussion of both the findings and the uncertainties concerning climate change. Trying to iron out dueling perspectives through the media and otherwise outside the scientific process will never be satisfactory. Nonetheless, some sides seem to be resorting to this approach. Brief comments on these issues cannot, in most cases, do them justice, but can perhaps provide some understanding of the issues, what is understood, and what the often underreported consensus views may be. I include below a few of my thoughts on some of the key issues raised and invite the Committee and its members to provide follow-up questions for response in writing.

1. Data for the full year clearly indicate that the global average surface temperature for 1995 was near or actually the warmest on record (see Figure 3)--and was likely the warmest since 1400 and even much earlier. What is most interesting is that 1995 set (or matched) the recent warming record even though there was no El Nino, the solar cycle was near a minimum, and ozone depletion was near record levels whereas in 1990 (the next warmest year) these comparative cooling influences were not present. Between these record years, the global average temperatures were suppressed mostly by aerosols injected by the Mt. Pinatubo volcanic eruption.

2. Global average temperatures have risen about 0.5°C (about 1°F) during the past 140 years (the period for which we have the best observations). As clearly summarized in the IPCC Second Assessment, the results of model simulations that include both greenhouse gases and sulfate aerosols, to the extent that we understand them, show good agreement with the observed record.

3. Climate model projections for the next century show a significant warming, with a central estimate of about 2.5°C (about 4.5°F). Such a rate of warming would be about four times the rate since the last century, creating the strong potential for significant environmental impacts. The reason for the acceleration in the rate of warming is that, because carbon dioxide has an average net lifetime in the atmosphere of perhaps two hundred years, it will build up substantially as coal use increases whereas sulfate aerosols get washed efficiently from the atmosphere within a few days (acidifying precipitation). The IPCC-organized scenarios of emissions assume that, because of concerns about acid deposition and because of the adverse health effects of small particles, sulfur dioxide emissions will decline in some areas while increasing in others. Hence, the warming effect of carbon dioxide will more and more exceed the sulfate influence.

4. The IPCC lower bound estimate of warming for the year 2100 has come down about 0.7°C (about 1.3°F) since their 1992 estimate--not due to model uncertainties or

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improvements, but to changes in the presumed scope of human activities. In 1992, the IPCC projected that the warming by 2100 would be 1.5 to about 3.5°C (or about 3 to 6.5°F); in 1995, the IPCC projected that the warming would be about 0.8 to 3.5°C (or about 1.4 to 6°F)-see Figure 4. Uncertainties are included in the IPCC estimates because they recognize that both models and societal projections have uncertainties (and these two factors contribute about equally to the range).The slightly lower estimates of warming, which are within the earlier range of uncertainties, had much less to do with uncertainties in the climate models themselves or their responsiveness to human activities than with the estimates of societal activities. To a first order approximation, the differences were caused by the inclusion of sulfate aerosols[1] and the early phasing out of CFCs in order to protect the ozone layer. Climate models are becoming even more representative of the global climate system, but that was not the cause of the reduced estimates.

5. Despite the projections of global warming of surface air temperatures, this does not mean that the tropospheric temperature [measured by the Microwave Sounding Unit (MSU) instrument] should be warming in exactly the same way. While much has been made of the observations that the 16 year MSU record doesn't show a warming of the atmosphere, there are several possible aspects to consider and detailed analyses are indicating the reason for the records giving different results (Dr. Christy covers this in his testimony). Furthermore, it is very problematic to draw conclusions about trends from such a short record. The somewhat longer radiosonde [weather balloon] record of tropospheric temperatures, which the MSU mimics quite well, does show overall warming over the past three decades, in long-term and general agreement with the surface record.

6. Regarding the supposed difference in the MSU and model-predicted rates of warming, such comparisons that have been done have been of fundamentally different quantities. To make the comparison, the model run that is used has been adjusted in several ways that are inappropriate. Quite simply, the comparison is totally inappropriate to do and is presented in a misleading way.

7. There are significant limitations in using the climate record to make empirical estimates of how the climate may change in the future. If we could, it would certainly be desirable to be able to either do an experiment or analyze evidence of past climate changes or the present behavior of the climate to determine how sensitive the climate is to human influences. A number of approaches have been tried (e.g., paleoclimatic, year-to-year variability, etc.), but they give quite diverse results and none are particularly satisfactory. About all that can be concluded, is that the sensitivity can't be lower than about the lower limit used by IPCC or we would have no chance at all of explaining how climate changed in the geological past, and that the sensitivity can't be much higher than the upper limit used by the IPCC or we could not explain the amazing stability of climate over the last 10,000 years before human activities started to warm the climate.

8. Human-induced climate change is now "discernible." A major scientific advance in the last few years has been the ability to search for patterns of climate change, not just changes in the global average change. This has been possible because more realistic cases have been run using the climate models. The IPCC conclusion recognized the

[1] Including the past increases in sulfate aerosols reduces the future warming expected from past human activities, and the inclusion of the future increase in sulfate aerosols (even assuming 75% control of sulfur dioxide emissions!) further limits the effects of the projected increases in carbon dioxide emissions, which were assumed to be the same as was assumed in 1992.

following four points: (1) the global average temperature of the latter part of this century is at least as high as for any time in the last six hundred years (the period for which we can reasonably construct temperature changes)[2]; (2) the temperature trend has been upward since the last century; (3) the latitude-longitude pattern of global temperature trend is unlike patterns associated with natural variability (including solar variations) and quite similar to the predicted response in models to increasing carbon dioxide and sulfate aerosol concentrations; (4) the vertical and pole-to-pole pattern of temperature change is unlike that for natural variability (including solar and volcanic variations) and in general agreement with changes from greenhouse gases, sulfate aerosols, and ozone depletion; and (5) the magnitude of the changes is about as estimated by models. While no one or two of these would be as convincing, the IPCC concluded, rather conservatively, that the "balance of evidence suggests that there is a discernible human influence on global climate."

Concluding Comments

In summary, the USGCRP is a broad-based research program focusing on the full range of issues that will determine the world that we pass on to our grandchildren and their grandchildren--the issues are that important. There is much that we do not yet fully understand, which is why we must have a strong and vigorous research program. There is also, and this is very important, much that we do understand and which cannot be dismissed.

In the area of climate change (not even considering the environmental consequences and other aspects described in the testimony of Dr. Watson), scientific consensus agrees that:

1. The concentration of carbon dioxide has risen by about 30% due to human activities. The concentration of methane has more than doubled due to human activities.

2. For carbon dioxide, the effective lifetime of carbon dioxide in the atmosphere is centuries, and about 15% of the concentration increase will not be removed over thousands of years and longer.

3. The influence of all such greenhouse gases, including water vapor, is to make the climate warmer--there is no question about the sign of the effect.

4. Past warm climates have been associated with higher greenhouse gas concentrations and past colder climates with lower concentrations.

5. The global average temperature has warmed about 0.5°C (about 1°F) since the mid-nineteenth century. This is evident in the surface temperature and ground temperature records as well as in ocean temperature.

6. Sea level has risen about 10-20 centimeters (about 4-8 inches) over the last century and mountain glaciers have been melting back, both expected from global warming.

7. Large stratospheric cooling has begun, an expected result of the carbon dioxide increase.

[2] There is emerging evidence from studies of low latitude glacial extent and melting that the present period may be as warm as any period since the last interglacial, some 120,000 years ago.

8. Sulfate aerosols are a plausible explanation for having contributed to suppression of the global warming expected from the increased concentrations of greenhouse gases alone, especially, but not exclusively, in the Northern Hemisphere. Likely controls will limit their relative influence in the future.

9. The warming patterns are not like those which might be expected from natural variability and there are no known causes (e.g., solar, volcanic) that would explain the changes.

10. When the world has been warmer in the past, the largest changes have occurred in mid- and high latitudes, and these changes have had dramatic effects on ecosystems such as forests and grasslands. Even the seemingly small changes of the past thousand years have had dramatic effects on societies--understanding these changes is vital.

The projections for the next century, given the rapidly increasing emissions of carbon dioxide that seem inevitable, envision changes several times larger than over the current century. Temperatures are projected to rise by 0.8 to 3.5°C (about 1.5 to 6°F) and sea level is projected to rise 15-95 cm (6 to 38 inches). This range reflects not only uncertainties in the models, but even more important, the range of scenarios for emissions and population. The USGCRP, as one of its many responsibilities, is sponsoring the research needed to find out more.

In FY-96, the likely appropriation is about $1.7B for USGCRP activities. While detailed consideration of this request is more appropriate for other hearings, it is interesting to note that this is just less than two pennies a day for every citizen of the United States-- a bit more than a penny a day for the Earth observing system and a bit less than a penny a day for research to understand all of these issues. My strong feeling is that this is an excellent investment in our future and that every American is more than getting their two cents worth each day.

Thank you, and I would be pleased to answer any questions.

Biographical Information for Michael C. MacCracken

Michael C. MacCracken was appointed Director of the Office of the U.S. Global Change Research Program (USGCRP) in September, 1993. In this role, he is responsible for supporting the interagency Subcommittee on Global Change Research (SGCR) of the Committee on Environment and Natural Resources (CENR) in its efforts to promote an integrated and cohesive research effort on such global change issues as climate change and greenhouse warming, ozone depletion and atmospheric chemistry, seasonal to interannual climate fluctuations, land cover change, and the ecological and societal impacts of global environmental change and to promote the development of methodologies for analyzing the consequences and evaluating the options for addressing global change.

Dr. MacCracken was born in Schenectady, New York in 1942. He received his B.S. in Engineering from Princeton University in 1964 and his Ph.D. degree in Applied Science in 1968 from the University of California, Davis/Livermore. Based on a question suggested by Dr. Edward Teller, his dissertation research involved use of a climate model to study the self-consistency of various hypotheses of the causes of ice ages. Following graduation in 1968, Dr. MacCracken joined Lawrence Livermore National Laboratory (LLNL) and for twenty-five years was a leader in their atmospheric and climate modeling effort. Early in his career, he led development of the San Francisco Bay Area air quality model, which was used to develop the Bay Area's successful air quality maintenance plan for photochemical oxidants. In his climate-related research, he also modified the global climate model used in his dissertation research to study the potential climatic effects of volcanic eruptions, of an increased carbon dioxide concentration, and of other climatic perturbations. During the 1970s, he led the project at LLNL to assess the climatic effects of supersonic transport aircraft and served as leader of a multi-DOE laboratory investigation (MAP3S) of the effects of sulfur emissions on air quality in the northeastern United States. Dr. MacCracken was appointed Division Leader of what became LLNL's Global Climate Research Division in October 1987, having served as Deputy Division Leader of the Atmospheric and Geophysical Sciences Division since its founding in 1974. In addition, he has been co-project leader of LLNL's study of the atmospheric effects of a nuclear war, an advisor to the Department of Energy (DOE) on the climate element of their carbon dioxide research program, and a co-leader of the joint University of California cooperative research project on global modeling. His most recent research activities included leading a special LLNL project to develop an Earth Systems Model incorporating atmospheric, oceanic, land surface, and biological components and serving as Chief Scientist for DOE's Computer Hardware, Advanced Mathematics and Model Physics (CHAMMP) program to implement the next generation of global climate models on massively parallel computer architectures. Dr. MacCracken is the co-author of several books and of many articles and reports in the general area of climate change.

From 1983 to early 1985, Dr. MacCracken was chairman of the American Meteorological Society's Committee on Climate Variations. From 1984 to 1992, he was U.S. co-chairman of the climate project under the US/USSR bilateral agreement on environmental protection, and he was co-editor of the joint US/USSR report *Prospects for Future Climate*, which compared the predictions of climate models with the paleoclimatic evidence for climate sensitivity. In 1986, he was co-author of the ICSU/SCOPE assessment on the physical and climatic effects of nuclear war and later of a similar report for the World Meteorological Organization. He served as co-editor and co-author of DOE state-of-the-art volumes issued in 1985 on projecting and detecting the climatic effects of the increasing carbon dioxide concentration. In 1990 he was chairman of a DOE Multi-laboratory Climate Change Committee that summarized findings on climate change issue in the book *Energy and Climate Change*, which was prepared in support of development of the National Energy Strategy. During the 1990s, he has been a co-author and contributor to chapters in the assessment reports of the Intergovernmental Panel on Climate Change (IPCC), and coordinated the U. S. Government reviews in 1995.

Dr. MacCracken is currently chair of the International Commission on Climate of the International Association of Meteorology and Atmospheric Sciences, for which he has organized two international symposia on climate in the past three years, and chair of the Atmospheric and Hydrospheric Sciences section of the American Association for the Advancement of Science (AAAS). He is also a member of the American Meteorological Society, the American Geophysical Union, the Oceanography Society, and the American Quaternary Association.

Dr. MacCracken is married and lives in Chevy Chase, Maryland. He and his wife Sandy have two sons in graduate school. From 1971 to 1978, Mike was an elected member of the Board of Directors of the Livermore Area Recreation and Park District (Livermore CA), serving as chairman in 1974 and 1978.

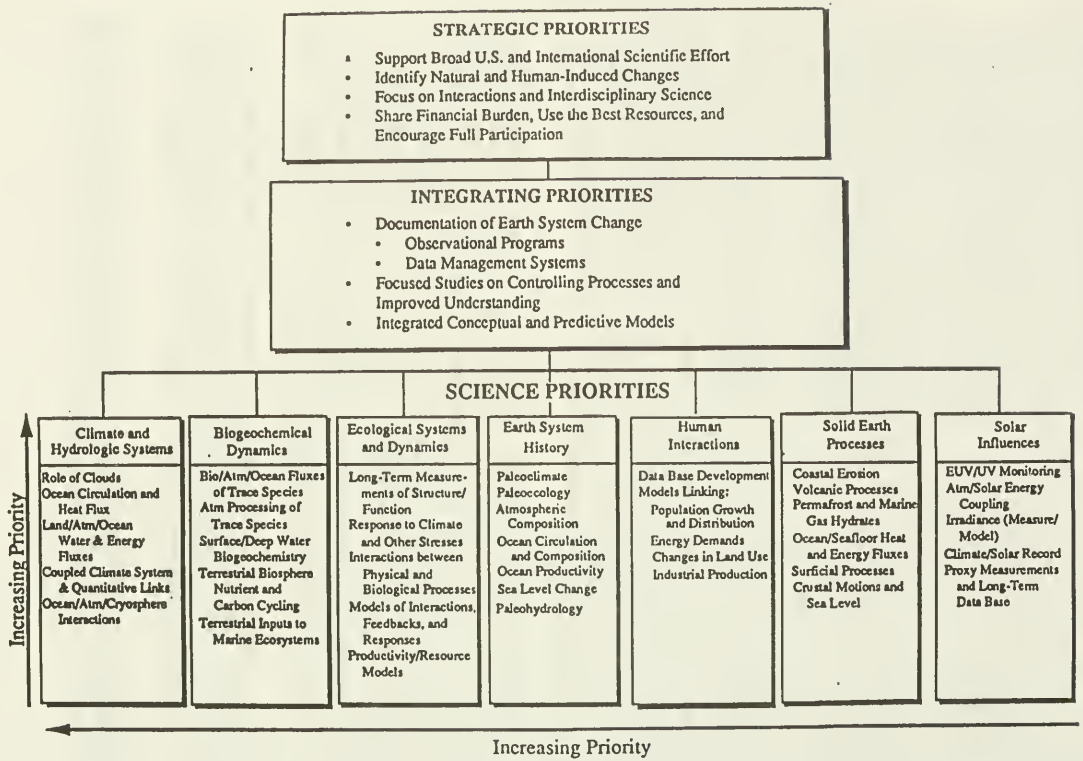


Figure 1 U.S. Global Change Research Program Priority Framework

May 3, 1995

USGCRP RESEARCH GOALS

EOS Measurements	Seasonal / Interannual Climate Events	Ozone Depletion / Surface UV	Land Cover Changes / Global Productivity	Decadal Climate Change
Atmosphere Set				
Cloud Properties		√	√	
Radiative Energy Fluxes		√	√	
Precipitation				
Tropospheric Chemistry	√	√	√	
Stratospheric Chemistry	√			√
Aerosol Properties				
Atmospheric Temperature				

Primary √ *Secondary* *Not Applicable*

USGCRP RESEARCH GOALS

EOS Measurements	Seasonal / Interannual Climate Events	Ozone Depletion / Surface UV	Land Cover Changes / Global Productivity	Decadal Climate Change
Atmosphere Set (cont.)				
Atmospheric Humidity		√		
Lightning		√		√
Solar Radiation Set				
Total Solar Irradiance	√			
Ultraviolet Spectral Irradiance	√			√

Primary √ *Secondary* *Not Applicable*

USGCRP RESEARCH GOALS

EOS Measurements	Seasonal / Interannual Climate Events	Ozone Depletion / Surface UV	Land Cover Changes / Global Productivity	Decadal Climate Change
Land Set				
Land Cover & Land Use Change	√			√
Vegetation Dynamics	√			√
Surface Temperature				
Fire Occurrence	√			√
Volcanic Effects			√	√
Surface Wetness				√

Primary √ *Secondary* *Not Applicable*

USGCRP RESEARCH GOALS

EOS Measurements	Seasonal / Interannual Climate Events	Ozone Depletion / Surface UV	Land Cover Changes / Global Productivity	Decadal Climate Change
Ocean Set				
Surface Temperature			√	
Phytoplankton & Dissolved Organic Matter	√			√
Surface Wind Field				√
Ocean Surface Topography			√	
Cryosphere Set				
Land Ice	√		√	
Sea Ice				
Snow Cover			√	

Primary √ *Secondary* *Not Applicable*

FIGURE 3

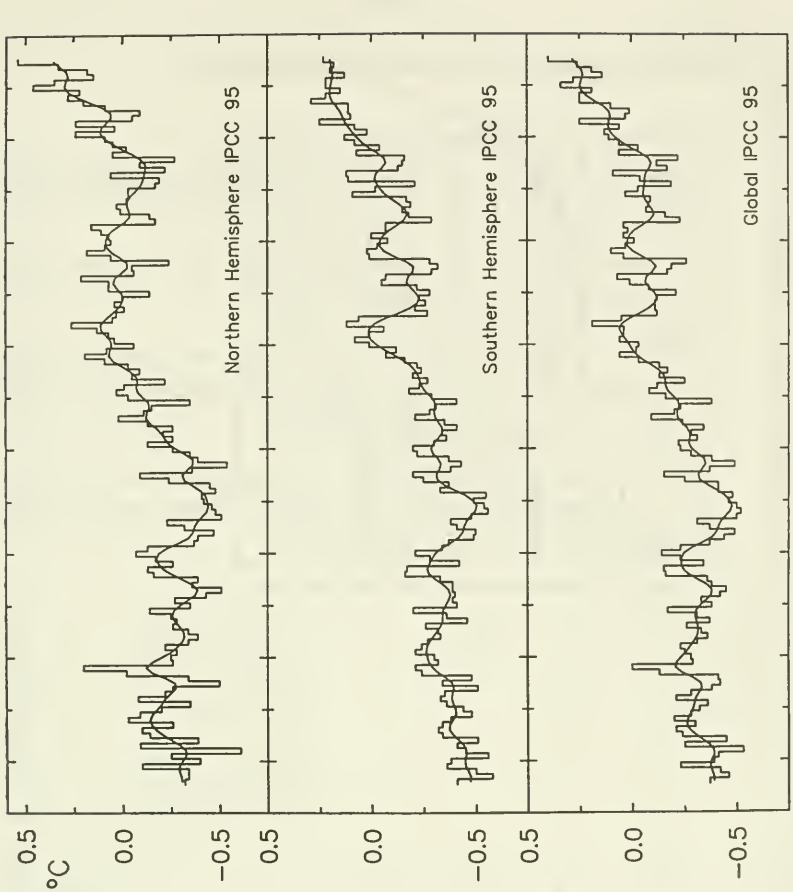
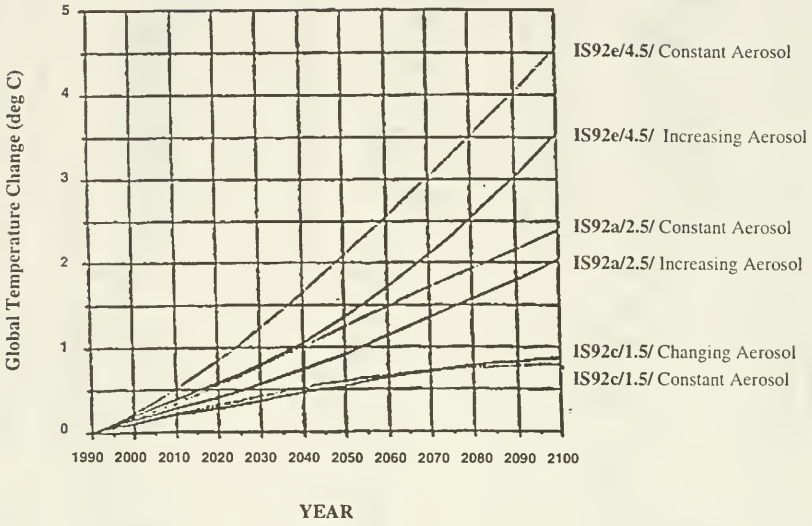
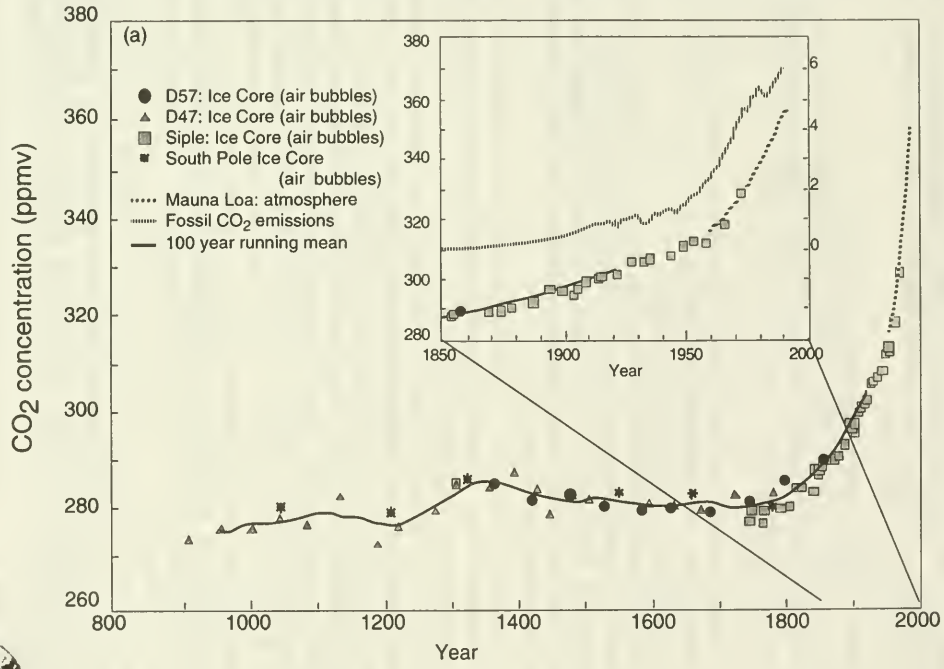

0.5
°C
0.0
−0.5
Northern Hemisphere IPCC 95
Southern Hemisphere IPCC 95
Global IPCC 95
1860
1880
1900
1920
1940
1960
1980
2000

FIGURE 4

Projected Changes in Global Temperature



CO_2 Concentrations Over the Past 1000 Years



SOURCE: Intergovernmental Panel on Climate Change. Summary for Policymakers, "Radiative Forcing of Climate Change: The 1994 Report of the Scientific Assessment Working Group of IPCC," page 9.

Chairman WALKER. Dr. Davis, you'll be next.

STATEMENT OF DR. ROBERT DAVIS, DEPARTMENT OF ENVIRONMENTAL SCIENCES, UNIVERSITY OF VIRGINIA, CHARLOTTESVILLE, VIRGINIA

Dr. DAVIS. Thank you, Chairman Walker.

I've been asked to testify briefly on climate and circulation change and climatic extreme events. That's a lot of ground to cover, of course, in five minutes, but I'll do the best I can to highlight some of the issues.

My primary area of research is in synoptic climatology, which involves changes in atmospheric circulation over time. Here I'm talking about surface and upper air winds.

Now we just heard recently from Dr. Balling that the general circulation models, which are actually based on fundamental circulation principles, have shown that there should be more warming in the polar regions than in the tropical areas. And this should especially be found in the winter time.

Now what this means in terms of atmospheric circulation is that we should expect our winter time weather, our winter time circulation to become more summer-like.

So I've been involved in some research on that particular topic and what we find in this particular example, we're looking at northern hemisphere circulation over the last 50 years.

What we found is that the ring of winds that go around the North Pole, what we call the Circumpolar Vortex, has actually expanded over time in the winter. This is exactly the opposite of what we should expect to happen if there are in fact increasing polar temperatures because of warming from greenhouse gases.

This result was actually corroborated independently by a colleague at Colgate University, unbeknownst to me, who was doing very similar research.

So here's one example of atmospheric circulation, which is a primary variable. It's related to surface temperatures, to precipitation, to basically surface weather conditions, that is not corroborating what the general circulation models and theory indicate should be happening.

I've also had the opportunity with some colleagues back on the circulation issue——

Chairman WALKER. Let me interrupt.

We have a vote underway and it's the Chairman's intention to keep this going at this point. So what I'm going to do is I'm going to run and vote while Roscoe Bartlett assumes the Chair.

I just wanted to let all of you know that that's what we're going to do, is go over, vote, and then come back and keep the hearing going as we do it.

Dr. DAVIS. So I'm to continue without you.

Chairman WALKER. Yes.

Dr. DAVIS. Okay.

Chairman WALKER. I've looked over your testimony. Roscoe will be here and I want to get back so we can get into the question and dialogue.

Dr. DAVIS. Okay. Thank you.

Chairman WALKER. Thank you.

Dr. DAVIS. Sir, may I continue?

Mr. BARTLETT. [presiding] Yes, sir, please.

Dr. DAVIS. Okay. Thank you. The next question would be has the atmospheric circulation changed over the entire hemisphere, and in fact, it hasn't.

This graph is showing what has happened, that most of the changes occurred over the western hemisphere. And in fact what we're seeing is an expansion of the circumpolar vortex, more cold air southward over the Pacific, and an expansion over the eastern part of North America and a contraction over Alaska.

This produces a kind of circulation pattern that results in more extreme climate over the northern hemisphere.

So what I'm saying is here is an example of a circulation change that has occurred that is the opposite of what is predicted by the general circulation models that causes more extreme events.

It is a mistake to say that every time that there's an extreme climatic event, that it's related to global warming. Sometimes they are. Sometimes they aren't. It's just fallacious to make that association all the time.

I've also been involved in some circulation on nor'easters. These are winter-time coastal storms that I think all of you live in Washington this winter are familiar with. If you watch the Weather Channel, you've seen people talking about nor'easters all the time. These are the storms that form in the wintertime that move up the coast and give us our heavy snowstorms along the east coast.

This graphic shows that over the past 50 years, the number of these storms overall has declined. That's what the top graph is showing.

However, the bottom graph, which is showing extreme nor'easters, what we call the Class 4 and Class 5 nor'easters, have actually increased in frequency, in the '70s, '80s, and if I continue this into 1995, we'd see that to be the case.

What's causing this?

It's caused by the same kind of circulation pattern that I was just talking about—more cold air masses traveling farther south into the United States, low pressure systems that form along the boundary between the ocean and this cold air mass that travel along the coast.

The fact that we have more extreme nor'easters is not an indication that global warming has kicked in, if you will. It's simply a function of an atmospheric circulation change that has happened since about 1960s or the mid-1950s.

In fact, this same kind of pattern was prevalent in the early part of the century, from the 1900s into the 1920s or 1930s, well before there were any greenhouse gas-induced effects.

Finally, there has been a lot of discussion about hurricanes. And if you look at the trend of Atlantic tropical storms and hurricanes over the period of record, this period goes back to 1961. You don't see any trends. Last year, there certainly were a lot of hurricanes, but that one year cannot be used as evidence of global warming effect.

If you look in the Pacific, where you have tropical cyclone typhoon records for the Pacific, where they get a lot more storms in

the Atlantic because of the size of the basin and the amount of warm water, there is also no trend.

And in fact, if you look at the sustained winds from Atlantic tropical storms, tropical cyclones—and I'm just about to finish—this shows that, actually, the winds over the Atlantic have decreased over time.

So in summary, I'd just like to make two final conclusions. One, I completely concur with Dr. Michaels on the need to maintain the accuracy and preserve our data record.

If it weren't for data, none of these studies could have actually been undertaken.

And finally, I'd like to say that I've heard a lot of this panel about a scientific consensus. Well, in my view, science doesn't operate by consensus. It operates by paradigms that are changed over time because of research.

Just getting a bunch of scientists together in a room and trying to get them all to agree doesn't mean that they are correct.

Thank you, sir.

[The prepared statement of Dr. Davis follows:]

Testimony before the U.S. House of Representatives Committee on Science
March 6, 1996

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I have been asked to testify on the current state of knowledge regarding global climate change with an emphasis on atmospheric circulation variability and extreme events. Additionally, I have been asked to comment on future data collection priorities that would best meet the needs of climate change researchers.

SUMMARY POINTS

CLIMATE CHANGE

1. The observed atmospheric circulation record over the past 50-100 years is not commensurate with the patterns expected to be generated by increased greenhouse gas concentrations based on either theory or models.
2. Extremes in climatic conditions (such as flooding or drought, increased storminess) are not, by default, signals of greenhouse warming. In fact, in many cases, they represent the opposite condition.

DATA COLLECTION PRIORITIES

1. The continuous monitoring and archiving of global weather data using internally-consistent methods is essential for an unbiased analysis of climate.
2. Models cannot be verified using modelled data--they must be validated or invalidated on completely independent data sets.

DETAILS

CLIMATE CHANGE AND EXTREMES

Measurements of atmospheric circulation (a term that encompasses wind flow at and above the surface) have been taken over much of the earth for 50 to 100 years or more. Circulation is a critical climate variable since it is closely linked to temperature, rainfall, and other weather events. Models that generate daily weather forecasts are founded upon principles that describe changes in the atmosphere's circulation. Similarly, General Circulation Models (GCMs), like the ones used as the motivation for the Rio climate treaty, are based on fundamental circulation principles.

The atmosphere's circulation varies on a daily, seasonal, and year to year basis, and often varies in a systematic fashion. For example, the core of strong winds in the upper atmosphere that circumscribe the earth's poles (the circumpolar vortex) expands in the winter, as cold, polar air travels equatorward, and contracts in the summer, allowing warm, tropical air to advance poleward. Variations in the position of the circumpolar vortex are closely coupled to seasonal temperatures. Furthermore, different orientations of the circumpolar vortex and jet stream influence surface weather conditions (like dry weather and clear skies versus precipitation) based on fundamental principles of atmospheric physics.

The developers of GCMs frequently state that, although their forecasts are not suitable for analysis on smaller spatial scales (regions or sub-regions), the models properly describe the larger-scale features of the atmosphere accurately. Thus, the model predictions for an atmosphere with double the pre-industrial concentrations of greenhouse gases should be basically correct over large areas.

Although individual GCMs differ substantially in their regional forecasts, most are in agreement with respect to some larger-scale features that should be expected in an enhanced greenhouse atmosphere. Tropical temperatures are expected to increase only slightly relative to polar temperatures. Furthermore, this polar temperature increase is predicted to be concentrated largely in the winter. Thus, the models predict a decrease (in comparison to current values) in the equator-to-pole temperature gradient. In response, the winter atmospheric circulation should become more summer-like, as represented by a weakening of the jet stream and a contraction of the circumpolar vortex.

Based on observations of the upper atmosphere taken since the late 1940s, the winter circumpolar vortex has actually exhibited a statistically significant expansion (Davis and Benkovic, 1992, 1994; Burnett, 1993). Others have detected a similar response using different analysis methods (Boer and Higuchi, 1980; Namias, 1980; Knox et al., 1988; Michaels et al., 1990;

Shabbar et al., 1990). This response is the opposite of what would be expected from a greenhouse warming influence. Furthermore, these observed, large-scale changes are not depicted by GCMs.

This expansion of the winter circumpolar vortex is not hemispheric but regional, and is primarily concentrated over the Pacific Ocean and eastern North America. The resulting average pattern results in stronger storms in the central Pacific (Kutzbach, 1970), higher frequencies of warm air masses in Alaska (Kalkstein et al., 1990), and declining temperatures and more cold air outbreaks in the southeastern U.S. (Karl et al., 1989; Rogers and Rohli, 1991; Stenger and Michaels, 1992). This predominant circulation pattern, which has been observed over the past two to three decades, is associated with more extreme climate variations over North America. However, this wind pattern is NOT what theory and models predict should occur with global warming. A very similar winter flow pattern existed at the beginning of this century, well before many anthropogenic greenhouse gases were released into the atmosphere.

In collaboration with researchers at the University of Virginia, I have developed a unique data base on the climatology of non-tropical coastal storms, frequently called "nor'easters," for the mid-Atlantic coast. Analysis of this climatology indicates that the late 1980s and 1990s were a period characterized by many strong nor'easters (Davis and Dolan, 1993; Davis et al., 1993; Jones and Davis, 1995). This is an example of an extreme event not related to a global warming signal. These storms form along the coast of the southeast U.S. in regions of strong temperature contrasts. Thus, they are associated with cold air masses over the Southeast--the type of situation produced by the observed circumpolar vortex configuration discussed previously.

Over the past few months, heavy snowfalls over much of the eastern U.S. have been attributed to global warming. Since these storms are almost always nor'easters, this argument is scientifically indefensible. Along the east coast, snowfall declines as temperatures increase. Heavy snows require a strong cold air mass to be in place over the region. Finally, the nor'easter responsible for the snow is driven by an upper air circulation pattern that is not commensurate with an enhanced greenhouse-gas atmosphere. Thus, none of the conditions necessary for major east coast snowstorms are indicative of a global warming signal.

Similarly, outbreaks of extreme cold air over much of the continental U.S. have been blamed on global warming. This, too, is unsupported by theory or observations. Air masses that form over the snowpack in the Canadian prairies, the ice-covered Arctic Ocean, or Siberia serve as the source of these cold air outbreaks. With increasing concentrations of atmospheric greenhouse gases, more warmth should be radiated to the surface, thus making these air masses warmer, not colder.

These comments may leave you with the impression that I am opposed to efforts to model the earth's climate. This is not the case. Models can serve a very useful scientific purpose, such as the proposition and testing of hypotheses. The use of GCMs to examine changes in greenhouse gas concentrations in the atmosphere is an appropriate and important scientific question. However, when the results of these experiments are used to influence public policy (both nationally and globally), then concerns about the various models' accuracy must be raised. The simple fact is that the current generation of GCMs are incapable of reproducing the historic climate of the earth sufficiently at anything but the broadest time and space scales. These modelled errors are not merely a function of lack of computing power--they underscore our lack of understanding of the atmospheric processes that govern the earth's climate.

For example, recent measurements of absorption of solar radiation by clouds has significantly altered our understanding of the planet's radiation balance (Cess et al., 1994; Ramanathan et al., 1994; Kiehl et al., 1995; Pilewskie and Valero, 1995). Clouds absorb 7 Watts per square meter more radiation than was previously believed This value is far in excess of the increase in radiation at the surface that is modelled to occur from a doubling of greenhouse gas concentrations. In other words, the cloud absorption error in the models (which is a fundamental aspect of GCMs) is significantly greater than the forcing that generates higher surface temperatures. One should then ask to what extent we should trust these GCM forecasts.

Furthermore, there must be some reality check on GCMs. I have been to numerous meetings where researchers critical of GCM output have been told that their particular concerns have been addressed in the latest model run that has not yet been released. Not only is it difficult to hit a moving target, but this approach guarantees funding in perpetuity since the next version of the model will purportedly resolve many of the defects evident in the previous run.

Until models are developed that can accurately recreate the observed climate history of the earth over the period of the observational record, then their forecasts should be kept out of the public policy arena. There is grave danger in basing policy on forecasts using models that are fundamentally flawed in their depiction of climatic reality.

This year the U.N.-sponsored Intergovernmental Panel on Climate Change (IPCC) released an updated report claiming that a consensus of 2500 world scientists now agree that global warming is here, thus erroneously leading people to believe that the debate has ended. The notion that there are 2500 active climate researchers knowledgeable on the pertinent issues is preposterous. The editorial process was carefully controlled to give the appearance of widespread agreement. My contribution serves as an enlightening example.

I was asked to submit a two-page statement on historic atmospheric circulation change in

light of increasing levels of greenhouse gases. My statement (Appendix A) discussed a significant body of research indicating that observed Northern Hemisphere circulation change is in agreement with neither theoretical nor modelled changes. My closing statement was "Thus, there is little consistent observational evidence in the Northern Hemisphere's climate history to indicate that the circulation has been significantly altered by increasing concentrations of CO_2 and trace gases."

The initial draft of this IPCC chapter contained absolute none of the information I provided. It did, however, state that much of the historic circulation data cannot really be used because of (allegedly irreconcilable) data inconsistencies, despite the fact that all of the studies I cited were published in respected, peer-reviewed journals. The chapter did, however, cite numerous studies supporting the opposite view that included papers that were still under review and were not available for scrutiny by the broader scientific community. I relayed these and other concerns in my comment section (Appendix B).

Not surprisingly, the final draft again included none of these concerns. In fact, the only aspect of my research cited (by another author) was the increasing frequency of intense nor'easters along the mid-Atlantic coast. The document leaves one to believe these nor'easter trends provide further evidence of more extremes caused by global warming, although I never stated or even alluded to this in my papers and presentations on the subject.

DATA COLLECTION PRIORITIES

Climatology requires accurate historical records. The maintenance of internally-consistent climatic observations of temperature, moisture, wind, and precipitation (and other variables) is essential if we are to answer questions about current and future climate variability and trends. For example, changes in types of instruments, observation times, elevation, or location can introduce so much error in a temperature history as to make the record unusable. Many of these errors are greater than the greenhouse-warming signal that scientists are attempting to detect. While new observations will be useful for weather forecasting, they will tell us nothing about historic climate change. No new earth observing systems should be implemented without very careful consideration of the measurement and archiving of data in a manner that is both commensurate with existing systems and useful for long-term climate research. (For example, it is encouraging that the climate community has been consulted on the proposed National Polar-orbiting Operational Environment Satellite System (NPOESS). It is essential that climate is not forgotten in these types of endeavors.)

The maintenance of an accurate and consistent network of atmospheric observations is sacred in climatology. These data are the ultimate arbiters in all debates about climate change.

They represent the challenge to which all GCMs must answer. There has been a recent, disturbing trend to use modeled "data" to verify and validate models. Some scientists will argue that these modeled values are actually superior to real observations. If this view were pervasive 40 to 50 years ago, we would not be having this hearing today. Models would show the earth heading toward a cataclysmic warming and there would be no reality check for these forecasts. The ultimate (and only meaningful) verification of models is a comparison to observations--the observational record must be maintained.

Presently, within the bowels of the National Climatic Data Center in Asheville, North Carolina, paper copies of millions of historic climate records from the 1800s and early 1900s are deteriorating. At current funding levels, these data will not be fully digitized until the middle of the next century and many may be lost before then. These extensive records, most of which have never been analyzed, would provide great insight into climate trends and variability if they were made available to the scientific community. I believe we must reevaluate our priorities. We must concentrate our efforts on the preservation of historic climate records, not on their destruction.

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APPENDIX A.

Text submitted to the IPCC for incorporation into Chapter 3 of the report--Observed Climate Variability and Change. This was submitted in May, 1994.

Variability and Changes in Northern Hemisphere Circulation

General Circulation Model prognostications exhibit substantial inter-model variability for forecasts of climate state parameters in double CO_2 scenarios, and atmospheric scientists are properly cautious in placing too much faith in these forecasts at regional and sub-regional (sub-grid) scales. However, most GCMs are in agreement with respect to some general planetary and synoptic-scale features that could be expected in a enhanced-greenhouse-gas atmosphere. One of these areas of agreement is the tropical-polar temperature gradient. With increasing concentrations of radiationally-important trace gases, tropical temperatures are expected to increase slightly whereas polar regions are anticipated to exhibit the greatest warming. Furthermore, this polar temperature rise should be concentrated during the winter, low-sun periods. This decrease in the equator-to-pole temperature gradient should, based on simple atmospheric thickness arguments, alter hemispheric circulation by decreasing the strength of the mid-latitude westerlies and/or producing an overall contraction of the circumpolar vortex. Therefore, examination of historical changes in atmospheric circulation should provide clues as to whether we are experiencing circulation changes that are commensurate with the current greenhouse enhancement.

One advantage of examining constant pressure (or height) fields is that these data tend to be less problematic than surface observations (even after rawinsonde errors). Systematic errors often contaminate surface data sets, such as changes in observation times, sites and elevations (Mitchell, 1953, 1958; Baker, 1975; Schall and Dale, 1977; Karl *et al.*, 1986), urbanization effects (Karl *et al.*, 1988; Balling and Idso, 1989; Jones *et al.*, 1990), and instrument measurement biases (Karl *et al.*, 1989; Legates and Willmott, 1990; Gall *et al.*, 1992). Thus, the magnitude of the observed surface climate change signal is often within the noise of the observations. However, upper atmospheric wind and height fields are spatially smooth at synoptic and planetary scales; thus, measurement errors, while present, are not as problematic.

A substantial literature exists on historical changes in circulation over the Northern Hemisphere. One common feature of changes in circulation states is that they are better described as step-functions rather than gradual trends. This follows from the Rossby wave regime that characterizes the mid- and high-latitudes: for example, a shift from a predominant three-wave vortex to two waves represents an abrupt change in the nature of the circulation at most locations in the hemisphere. These types of abrupt transitions have been noted by numerous researchers. Lamb (1968) observed that the Northern Hemisphere circulation changed from primarily zonal to meridional *circa* 1950. Dzerdzeevskii (1962, 1969) identified three circulation epochs: meridional from 1900-20; zonal from 1920-50; and meridional after 1950. Others detected important circulation changes over smaller regions (*e.g.*, Makrogiannis *et al.*, 1982; Briffa *et al.*, 1990).

Gridded pressure and geopotential height fields are frequently used to assess circulation changes. Knox *et al.* (1988) and Shabbar *et al.* (1990) detected a statistically significant shift from higher to lower 50 kPa heights over the Northern Hemisphere that occurred in 1963. Zonal to meridional shifts in the 1950s were noted by Kutzbach (1970) and Kalnicky (1974). Some of these shifts have been corroborated through the analysis of temperature records (Angell and Korshover, 1977; van Loon and Williams, 1977). Declining thicknesses were found throughout the 1950s and 1960s for both North America and the Northern Hemisphere (Boer and Higuchi, 1980; Namias, 1980; Michaels *et al.*, 1990).

Another approach involves the temporal analysis of individual geopotential height contours to examine changes in the size and shape of the circumpolar vortex at various pressure levels. Using data starting in 1963, Angell and Korshover (1978, 1983) observed an expanded 30 kPa vortex in the early 1960s and a more contracted vortex in the early 1980s. Later, Angell (1992) detected a significant vortex contraction in the late 1980s. In an analysis of January 50 kPa circulation from 1947-90, Davis and Benkovic (1992, 1994) identified a statistically significant 133 km expansion of the vortex in 1966, which was confirmed by Burnett (1993). This expansion was most pronounced over the North Pacific and over eastern Canada, while a significant contraction occurred only over western North America. This vortex configuration corresponds to deepening of the Aleutian Low (Kutzbach, 1970), enhancement of the positive phase of the Pacific-North America (PNA) teleconnection pattern (Reiter and Westhoff, 1982; Yarnal and Leathers, 1988; Shabbar *et al.*, 1990), increasing frequencies of warm air masses in northwestern North America (Kalkstein *et al.*, 1990), and declining winter temperatures and more cold air outbreaks in the southeastern United States (Karl *et al.*, 1989b; Rogers and Rohli, 1991; Stenger and Michaels, 1992).

At the surface, statistically significant declines have been detected in the frequency and magnitude of both migratory and semi-permanent anticyclones (Perry, 1971; Wagner, 1971; Angell and Korshover, 1974; Zishka and Smith, 1980; Harman, 1987; Sahsamanoglou, 1990a,b; Davis *et al.*, 1994). Significant declines in the central pressure of both the North Atlantic and North Pacific Subtropical Anticyclones suggest that there has been either a hemispheric or global redistribution of atmospheric mass over the last 100 years (Davis *et al.*, 1994).

The relationships between observed circulation variability and GCM prognostications are unclear. The expansion of the circumpolar vortex in winter contradicts both theory and model forecasts that support vortex contraction. Furthermore, according to GCMs, in an enhanced "greenhouse world," lower stratospheric temperatures should decline, but the circumpolar vortex was observed to contract at 30 kPa (although cooling is observed from 30-10 kPa over the last 30 years (Angell, 1991)). Some scientists suggest that climate variability will increase, despite the anticipated weakening of the polar jet with a reduced hemispheric thermal gradient, and their view has been supported by the presence of persistent meridional flow. Finally, various GCMs exhibit both strengthening and weakening of the subtropical anticyclones (Washington and Meehl, 1989; Houghton *et al.*, 1990; Rind *et al.*, 1990). Thus, there is little consistent observational evidence in the Northern Hemisphere's climate history to indicate that the circulation has been significantly altered by increasing concentrations of CO_2 and trace gases.

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APPENDIX B.

Comments submitted to the IPCC at their request regarding the draft version of the document. These comments were submitted in July, 1995.

PART I. REVIEWER

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PART II. REVIEWER COMMENTS

(I reviewed Chapter 3 and the Summary for Policymakers, as these topics represent my primary areas of expertise and research interest.)

COMMENTS ON CHAPTER 3

General--This Chapter as well as the Policymakers Summary do not reflect the appropriate balance one would expect from a scietific document. In reading the text, one not familiar with the specifics would be lead to believe that the authors are trying to expound a particular point of view regarding climate change and variation rather than an objective airing of the issues which includes rival viewpoints. I strongly encourage the editors to carefully review the text for instances in which research findings which seem to counter greenhouse-gas warming "beliefs" are treated lightly or dismissed. I will point out a few examples below. The IPCC would be better served by developing a balanced treatment than by scientific advocacy.

General--I am very concerned about the inclusion of citations of manuscripts that have been submitted for publication (but not accepted) and even, in some cases, of manuscripts being prepared for submission. This does not meet the standards of publication in the sciences and particularly does not allow for proper peer-review of these research results. Furthermore, extensive results derived from "personal communication" are unacceptable. While I appreciate that this report has taken long months to compile, and that some of these citations will be updated, there must be some minimum criterion for inclusion of citations herein.

General--I am likewise concerned about the lack of statistical validity of some of the results. For example, frequent mention is made of declining or increasing "trends", but in most instances the statistical significance of these variations is not included. For example, it is fine to say that the global temperature has increased from 0.3 to 0.6C since the late 1800s, but not that this is a trend unless it is statistically significant, in which case it is demonstrably different from zero (or no trend). To avoid confusion, I recommend that trends be referred to as "significant" or "non-significant."

General--(a minor point) Technically, temperatures can only be high or low, they cannot be "hot", "warm", or "cold." (When conditions are warm, temperatures are high.)

CHAPTER 3

Page 1, lines 15-17--this trend is non-significant both before and after adjustment

Page 1, lines 22-25--The implication (unstated) is that the MSU data cannot be trusted. This relates to the overall balance issue. Are the "small" differences between the radiosonde and satellite observations statistically significant? Are the differences large enough to discount either data set? If so, how does one know which one to trust?

Page 2, line 11--trend?

Page 2, lines 21-28 and throughout chapter--Since one of my active research areas involves historical changes in atmospheric circulation, this section is of great interest to me. I am disappointed with the emphasis on ENSO (and NAO) at the near exclusion of all other circulation research. From my reading of this literature, researchers have had little success relating positive or negative SOI values with anything but general increases or decreases in temperature and precipitation, and then only over very specific regions (like the Equatorial Pacific). Further, because of the heavy reliance upon one extreme event (1982/83), these studies do not have statistical veracity. It is incorrect, in my view, to try to attribute any substantial portion of the variance in climate to ENSO, which at best accounts for less than 10% of the variability.

I do, however, realize that there are others whose views on this issue differ substantially from my own. I ask, however, that a balance be presented, and that other circulation studies (many of which are quite important) be included in this section.

One bullet that could be added here is as follows:

* Observational evidence of historic circulation change shows expansion of the Northern circumpolar vortex in winter, increased meridional flow, and a weakening of the polar jet over the Western Hemisphere over the past 2-3 decades (compared to previous periods).

Finally, evaluation of Figure 3.18 shows several periods of strong positive SOI activity similar to the 1990-95 period, including an apparently stronger period in the decade from 1911-1920. Thus, this recent El Nino is not "highly unusual" with respect to either strength or duration.

Page 3, lines 13-15--Data in Figure 3.22 show the highest temperatures in the 1930s. Instead of "recent decades", say "the 1930s," which is more clear.

Page 3, lines 25-26--This last sentence should be toned down.

Page 4, lines 5-10--While all of these questions are interesting and important, the overriding questions with respect to all of them are: 1) are they outside of the range of normal climatic variability, and 2) are they consistent with theoretical climate changes suspected to result from increased greenhouse gases. The perception of the informed non-climatological community is that more severe conditions (temperatures, hurricanes, floods, tornadoes, disease, etc.) are related to "global warming," when in fact they may be indicators of just the opposite. This should be mentioned somewhere in the Chapter and also in the Summary for Policymakers.

Page 5, lines 29-30--This is an example of lack of balance. Correction: "Because arid regions account for only 14% of the earth's surface, desertification alone cannot account for all of the observed global temperature increase."

Page 7, line 3--Figure 3.4 should be altered to indicate those regions with statistically significant positive and negative trends.

Page 7, line 32--Add, "Thus, there is considerable uncertainty and scientific debate regarding the existence or extent of high latitude temperature changes."

Page 12, line 13--delete "temporary", since no one knows whether the warming is "permanent".

Page 17, lines 7-11--Balance. Why must a conditional clause or sentence be added every time there is some data or study indicating that current climatic conditions might not be that unusual? Each statement of the latter is not followed by a similar conditional clause arguing the opposite viewpoint.

Page 17, lines 16-27--The Legates and Willmott "Gauge-corrected" precipitation climatolgy results should be included in this section. See Legates and Willmott, 1990, International J. Climatology,

10, 111-127 and related papers.

Page 20, lines 35-40--Lins and Michaels concluded that streamflow was high in regions that did not have increased precipitation, and they thus assumed this increase to be related to decreased evapotranspiration and increased cloud cover. This important point is not clear in this section.

page 27--see my comments above related to page 2, lines 21-28.

Page 27, lines 9-11--replace this sentence with "Changes or variations in the atmospheric circulation are inextricably linked to observed changes in other climatic variables, including temperature and precipitation."

Page 27, lines 23-24--ENSO and the NAO are no more or less reliable than the PNA, the "Index cycle", or any other circulation measure. As I stated above, I don't feel this section reflects the balance of the work that has been done on this topic. Please see my submission (to G. Gruza) for a review or let me know if you need a copy. Thank you.

COMMENTS ON SUMMARY FOR POLICYMAKERS

SPM 1, lines 10-15--note that the most important greenhouse gas is water vapor.

SPM 1, line 14--we cannot state with certainty that there will be a warming because of feedbacks. Change the word "will" to "may."

SPM 1, line 27--"which may or may not be realized..."

SPM 2, line 7--add "but have not yet properly accounted for the various and complex interactions of the governing physical laws."

SPM 3, line 16--Be specific, what portion of the warming can be attributed to urbanizaiton and desertification? Give a range of values.

SPM 13, lines 19-21--These new data are important and should be added to the summary on SPM 3 between lines 11 and 28.

SPM 13, line 24--regular balloon observations have been taken since 1947, not 1958.

SPM 15, lines 29-30--My research has indicated a period of increased storminess which I related

to a stronger land/ocean thermal gradient in winter. The circulation pattern that causes this is not consistent with GCM projections or theory regarding "greenhouse-gas-induced" climate change.

SPM 16, lines 19-20--add "...climate forcing, although it should be able to depict observed historic climate variations."

SPM 20, line 26--Will not more carbon be fixed in areas where growth is enhanced? It is unfair to discuss retreating forest stands without incorporating regions where growth will increase due to enhanced precipitation, etc. (as was documented in Chapter 3).

SPM 23, lines 5-13--The contention that there is close agreement between the MSU and modelled data is based upon two manuscripts, one which has only been submitted and another that is "in preparation." While this statement may ultimately be deemed true, it also may be determined to be false. Thus, at this time, it is merely speculation or opinion and does not merit inclusion in this document.

SPM 23, lines 14-15--This sentence implies that the authors understand climatic cause and effect. In my opinion, this document does not provide sufficient evidence that recent observed climatic conditions are beyond the range of natural variability.

Thank you very much for requesting my input. Please let me know if you have any questions regarding my review, and best of luck on your work on the next draft.

Bob Davis

Mr. BARTLETT. Thank you very much.
Dr. Christy?

STATEMENT OF DR. JOHN CHRISTY, EARTH SYSTEMS SCIENCE LABORATORY, UNIVERSITY OF ALABAMA AT HUNTSVILLE, HUNTSVILLE, ALABAMA

Dr. CHRISTY. Thank you. It's an honor to be here.

I'm here to report on a success story. That's a story about a government scientist and a university professor that actually worked together and got something done.

Dr. Roy Spencer, a NASA scientist, and I began investigating temperatures measured from satellites in 1979, to microwave sounding unit, or MSU.

These satellites were designed to provide information for daily weather forecasts and not for climate change.

No one would have thought 15 years ago that they would have had something valuable in them relative to global warming debate until we came along.

The temperature of the global atmosphere—let's go ahead and put that up.

That top fuzzy line is the global for the last 17 years and one month. It has a declining trend of minus 0.05. That's of interest because surface data sets show a rising trend, depending on which one you use, of plus 0.09 to plus 0.19, or just in the opposite direction and of greater magnitude.

We think the MSU issue is a remarkable data record, but it has lots of ups and downs, as you can see. And I'm going to skip right to the last line on the diagram here.

When you account for forces that we know about and can quantify, you end up with a global warming trend in that last line there of plus 0.09. You can see it written there. That is the trend relative to something you might want to compare with a climate model.

Now these latest results go almost with the global climate model results that show a warming rate of about 0.08 to 0.30 for the current period in our history, once air pollution or sulfate aerosols are described.

So the 0.09, as you see there, barely fits into the 0.08 to 0.30 range, just barely into it. So it's not inconsistent with that, but it's certainly not inconsistent with natural variability as well.

Now the Spencer-Christy MSU data set has been used by some as evidence that global warming is not important and that undercuts the need and urgency for programs such as MTPE.

I strongly disagree with that interpretation.

By showing that the Earth's rate of warming is slower than predicted, by earlier models and data sets, it may remove some of the urgency for greenhouse gas controls and it perhaps gives us more time to make sure we know what's going on with the system as a whole before action—or drastic action, I should say—is taken.

Now I believe that honest and open scientific debate, with precise data such as this, is really the key to making the right kind of decisions for society.

The MSU data set would not have been developed without the competitiveness and entrepreneurial spirit fostered by having sepa-

rate NASA science centers and a broad research university program.

Industry should recognize that good science and good data are their allies, whether in debates on acid rain or global warming.

Now one valuable benefit of a program of Earth observations in the improvement in weather forecasts, and particularly out to two or three weeks, or even to seasonal timescales. The potential economic impact of improved long-range forecasts would be enormous. Every sector of our economy, especially energy production and consumption, agriculture, transportation, insurance, recreation, and so on, would have more value-added if they knew further information about the weather.

I want to say, too, that there's a strong and continuing program in space-based observation is what we need. It has this benefit as well.

There will be extreme climate events in the future. There's no way to get around that. Without a continuing program of research that places these climate variations in proper perspective and reports with improving confidence on their specific causes, we will be vulnerable to calls for knee-jerk remedies to combat climate change, in quotes, which will likely be unproductive and economically damaging.

We can protect ourselves from such pitfalls by improving our ability to measure what the climate is doing and determine the causes for its variations.

I'll stop right there and wait for questions.

[The prepared statement of Dr. Christy follows:]

Testimony
U.S. House of Representatives
COMMITTEE ON SCIENCE
6 March 1996

John R. Christy
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1. Concern for Climate Change

In the 1980's, Global Warming due to the enhanced greenhouse effect came to be perceived as a serious threat to the planet's ecological and societal sustainability. This concern was based primarily on estimates of global warming and other climate changes from numerical models of the Earth's climate system. (This perception was reinforced by a few hot, dry summers in the eastern U.S. which constituted for some people the "smoking gun" of climate change.) While the development of models is critical to our future ability to examine what we may be doing to alter the climate of the Earth, many scientists acknowledge that models are still rather simple representations of the complex processes that control the Earth's climate.

The observational evidence for enhanced greenhouse global warming is also less than clearly defined. While all surface-based global temperature data sets indicated warming of 0.3 to 0.6°C since the last century, the complete source of this warming is still unknown. First, the Earth was evidently coming out of a relatively cold period in the 1800's so that warming in the past century may be part of this natural recovery. Data sparseness and reliability are somewhat suspect in the early years of the thermometer climate record and remain a concern even today when the shrinking network of stations is attempting to capture relatively small variations. Local land use changes may also have added additional warming not connected with greenhouse gases.

With this background, scientists recognized that we did not have an observing system in place with adequate means to truly monitor the health of the planet or to provide the data needed to validate and improve the models of the Earth System. One obvious limitation of information about the atmosphere was the lack of true global coverage. NASA's EOS was conceived to provide these critical data.

2. The Microwave Sounding Unit data set

I am here to report a success story - a story that involves U.S. Government scientists and managers who collaborated closely and productively with university scientists. In 1989, the EOS data were a decade or more away. So,

to test the ability of satellites to monitor the Earth, Dr. Roy Spencer, a NASA scientist, and I began investigating temperatures measured by the existing TIROS-N family of weather satellites (average life span was only four years each). These satellites were designed to provide information for daily weather forecasts, not for answering questions about global climate change.

The instrument of interest to us was the Microwave Sounding Unit (MSU), identical copies of which were flown on all of NOAA's operational polar orbiters since 1979. The MSU measures the intensity of weak microwave radiation emitted to space by oxygen in the air. The magnitude of this intensity is proportional to air temperature, so with global coverage by the satellites we could compute the true globally-averaged air temperature. Two specific layers have lent themselves to accurate measurements: 1) the lower troposphere, or the lowest 7 km of air next to the surface, and 2) the layer at 17-21 km, or lower stratosphere.

Putting together a climate record from multiple satellites involved collecting a huge volume of data and was a remarkable achievement in and of itself. It is a tribute to the current government system and the vision of scientists at the National Center for Atmospheric Research (NCAR) that those data (with little perceived market value at the time) were saved and archived. The MSU data products are now almost priceless in the global warming debate in having established a precise historical record of the Earth's temperature over the last 17 years.

It was our good fortune that my call to NCAR asking about the possibility of obtaining the MSU data came one week before a previously scheduled, major NCAR project to copy all satellite data from an old, outdated storage system to a newer one was to begin. Thus, forewarned that Spencer and I believed the MSU data were of some unique value, NCAR kindly extracted the necessary data (only 2% of the total) for us at only the marginal cost of the extraction process. This relatively "free and open" attitude concerning data availability was the key to our success in creating the MSU data set, since obtaining the data from a cost-recovering data center would have been prohibitive (the quote was over $1 million) for the speculative value of the MSU data for climate monitoring.

The computing facilities for our own massive processing task were provided by NASA's Marshall Space Flight Center, and we had the enthusiastic support of the Earth Science and Applications Division. After several months of tedious data analysis, we were able to construct various data sets with exceptional precision and continuity. As shown in Figure 1, the particular technique we eventually developed allowed the MSU data to be independently validated by two different means.

Our data sets begin with January 1979 and continue to this day. We have been fortunate that two of the four MSU channels have performed exceptionally well on each of the nine satellites that were launched at intervals of about two years. It was critical that at least one satellite in functioning condition was orbiting

when a new satellite was launched, because we required a period of overlap for precise intercalibration. (Only two satellites are operational at a given time).

3. The temperature of the lower atmosphere

The temperature of the global atmosphere is shown for the lower troposphere and lower stratosphere in Figure 2 (courtesy R. Spencer). Since we live in the lower troposphere, that time series has received the most attention. You will notice that there are large variations, both month-to-month and year-to-year. Because these variations are independently observed by two satellites, we know they are real. The trend in the time series is slightly downward (-0.05°C/decade or -0.09°F/decade). It is this relatively flat trend when compared to surface data (which show warming trends since 1979 of +0.09°C to +0.19°C/decade, depending on which data set is cited) that has attracted attention to the Spencer-Christy MSU data set.

Though the MSU temperature record has demonstrated high precision, there is also an element of ambiguity in the measurement. The layers measured by the MSU are several kilometers deep. Any intra-layer variability, therefore, would be masked by the vertical average. For example, a warming trend at low levels and a cooling trend at upper levels of one layer would be seen as no trend in the MSU vertical average.

One of the reasons the surface thermometer data have shown greater warming in the past 17 years is due to the fact that in continental regions the surface temperature responds with greater variation than the deep layer of air above. Over oceans (and in the global average), the opposite occurs. In the past 17 years there has been a tendency for the atmosphere over land areas to show warming (which is greater in the surface air response) while the atmosphere over oceans has exhibited cooling (greater effect in the MSU record). This pattern is thought to be due to natural variations. The net effect in the global average is a relative difference in the trends between surface air and the deep atmosphere. Thus, the uneven warming/cooling distribution of the past 17 years accounts for part of the difference.

Other differences are due to areas poorly sampled or not sampled at all by the surface network, as well as to some urban warming or land-use changes around many of the thermometers. It is a monumental achievement to construct a record of surface air temperatures, and most of these data sets have been subjected to many careful corrections to account for these non-natural temperature impacts.

Because of its precision and true global coverage, we believe that the MSU data set is the most robust measurement we have of the Earth's bulk atmospheric temperature. At the same time, it is still a relatively short data set for climate studies. As indicated in Figure 2, the data contain both long and short period fluctuations. To be useful in the global warming debate one must understand and carefully account for fluctuations in the data that may be masking or dominating the anticipated enhanced greenhouse signal.

4. The causes of the temperature variations

In a recent study, Dr. Richard McNider, also of the University of Alabama in Huntsville, and I looked for the causes of these fluctuations. We found that by accounting for the influence of tropical Pacific Ocean temperatures (El Niño) and the cooling effect of volcanoes, we could explain over 60% of the monthly variations (Fig. 3). These natural, shorter-term fluctuations indicate to us how much the global temperature responds to specific causes. Once calculated and removed, we see that without El Niños and volcanoes, the temperature trend of the past 17 years is upward (+0.09°C/decade or +0.16°F/decade, Fig. 3, bottom). What is causing this upward trend? We do not know for sure. It may be the enhanced greenhouse effect. At the same time there could still be a longer term trend in the data due to variations in aerosols, water vapor, or other unknown factors that are masking the true magnitude of the greenhouse effect.

The latest results from global climate models, which include the cooling effects of air pollution, indicate warming rates for the Earth of +0.08°C to +0.30°C/decade for the latter part of the 20th century. These are about half of the warming rates predicted a few years ago, when only increases in greenhouse gases were modeled. The present warming rate of +0.09°C/decade observed in the MSU data is barely within this model range, and yet is not inconsistent with fully natural variations on decadal time scales. Therefore, uncertainty remains as to the cause(s) of the trend the MSU has measured.

Why is there a discrepancy between the models' estimate of global warming and what the MSU data have shown? One must remember that temperature is essentially a response parameter. The MSU data in Figure 2 show us what has been happening to the climate but not why. A key goal of efforts to study the planet from space is to provide heretofore unmeasured data that can provide an understanding of why the Earth system behaves as it does. I believe that new observables such as aerosols, rain structures, water vapor distributions and surface characteristics, when used in conjunction with the MSU data set will provide answers to these questions. Our work demonstrates that satellites can be used to monitor the Earth on decadal time scales and that the vantage point of space offers the only truly global view of the Earth system that can give robust measures of key variables.

The Spencer-Christy MSU data set has been used by some as evidence that global warming is not important, which then undercuts the need and urgency of programs such as MTPE. I strongly disagree with this interpretation. By showing that the Earth's rate of warming is slower than predicted by earlier models or surface data sets, it does, perhaps, remove the sense of urgency to enact greenhouse gas controls or to shut off scientific debate. But most importantly, the slower warming rate in the last two decades in effect gives us the security of time for data from near-future missions to be used within the debate.

I believe that honest and open scientific debate with precise data is the key to making sound societal decisions. The cultivation of diversity of scientific thought is critical to vigorous debate. The MSU data set would not have been developed without the competitiveness and entrepreneurial spirit fostered by having separate NASA science centers and a broad university research program. Industry should recognize that good science and good data are their allies, whether in debates on acid rain or global warming. It is now more critical than ever that we study the planet's health with new diagnostic devices. Any delays in doing so may mean that the length of data records available to scientists is reduced and cannot be used in the societal debates.

The disagreement between models and the MSU simply illustrates how little we understand about the complexities and factors that control the Earth's climate. Every month Roy Spencer and I process the newly arrived data and eagerly look at the month's temperature to see what is happening to the Earth. If we knew everything we needed to know about the Earth's system, we would not be as anxious about the results. I look forward to the time when new data from planned satellite sensors, coupled with an understanding of the Earth's climate system developed under research programs emphasizing global change, make surprises in the MSU global temperature as rare as being surprised by land-falling hurricanes in this era of weather satellites.

5. The temperature of the lower stratosphere

The record of the lower stratosphere is fascinating in its own right. Clearly, here is an example of global change on the scale of years to decades (Figure 2). The two conspicuous warming events were due to explosive volcanic eruptions - El Chichon (1982) and Mt. Pinatubo (1991). The aerosols injected by these explosions high into the stratosphere caused the warming through radiative interactions. Notice, however, that once the aerosols settled out, the global stratospheric temperature fell to levels below those observed at pre-eruption. It is widely thought that the loss of stratospheric ozone, both naturally from volcanic events and from human-generated chemicals, has caused this overall cooling. The increase in greenhouse gases, which will cause stratospheric cooling, is probably a factor as well.

The 1995 annual stratospheric temperature was the lowest annual value ever measured by satellite, and January 1996, was the coldest single month on record. Something is changing in the lower stratosphere -- the temperature tells us that much, but cannot specifically indicate the cause. (Others have much more experience here.) The extent of the stratospheric cooling trend points to the need to fully understand its cause.

6. Concluding remarks

Continued monitoring of global temperature through the Spencer-Christy method is expected as long as our good fortune holds and the two orbiting instruments do not fail (which almost happened recently). Thus, we should

continue to provide the scientific community with precise temperatures for deep atmospheric layers.

In any weather variable, e.g. temperature, rainfall, etc., it is the shorter-term fluctuations (week-to-week) that cause the greatest impact on human productivity. One valuable benefit of a program of escalating Earth observations is the resulting improvement in weather forecasts -- particularly out to two to three weeks and even to seasonal averages. The potential economic impact of improved long-range forecasts would be enormous. Virtually every sector of our economy is sensitive to weather, especially those related to energy production and consumption, agriculture, transportation, insurance and recreation. Improved knowledge of coming weather situations would be used to add value to the products and services generated by these industries.

A strong and continuing program in space-based atmospheric research has this more subtle benefit as well. There will be extreme climate events in the near future because that is the nature of weather and climate. Without a continuing program of research that places climate variations in proper perspective and reports with improving confidence on their causes, we will be vulnerable to calls for knee-jerk remedies to combat "climate change," which likely will be unproductive and economically damaging. We can protect ourselves from such pitfalls by improving our ability to measure what the climate is doing and determine the causes for its variations.

In simple terms, the "Global Climate" is our patient. We have taken its temperature in a few places and have seen just enough change to cause concern. Before prescribing any powerful medicine though, the patient should be given a complete physical as soon as possible, so we may then make the proper diagnosis and chart a correct course of action for the benefit of all.

References:

Christy, J.R., 1995: Temperature above the surface layer. *Climatic Change*, **31**, 455-474.

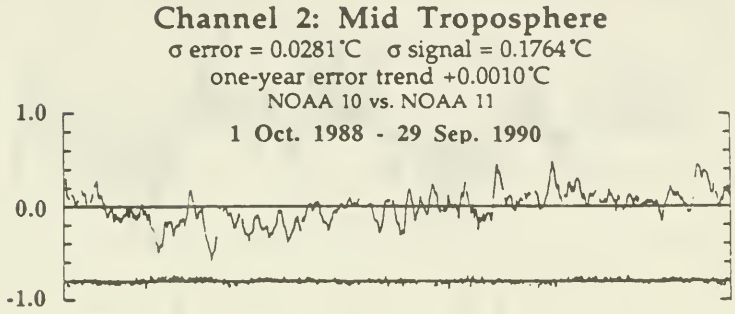
Christy, J.R. and J.D. Goodridge, 1995: Precision global temperatures from satellites and urban warming effects of non-satellite data. *Atmospheric Environment*, **29**, 1957-1995. (Fig. 1 (Top) of testimony taken from this article.)

Christy, J.R. and R.T. McNider, 1994: Satellite greenhouse signal, *Nature*, **367**, 325 (27 January 1994). (Fig. 3 of testimony, updated, taken from this article.)

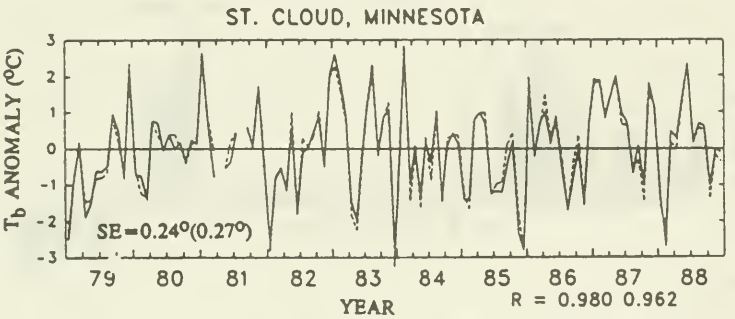
Spencer, R.W. and J.R. Christy, 1990: Precise monitoring of global temperature trends from satellites. *Science*, **247**, 1558-1562 (30 March 1990).

Spencer, R.W. and J.R. Christy, 1992: Precision and radiosonde validation of satellite gridpoint temperature anomalies. Part I: MSU channel 2. *Journal of Climate*, **5**, 847-857. (Fig. 1 (Bottom) of testimony taken from this article.)

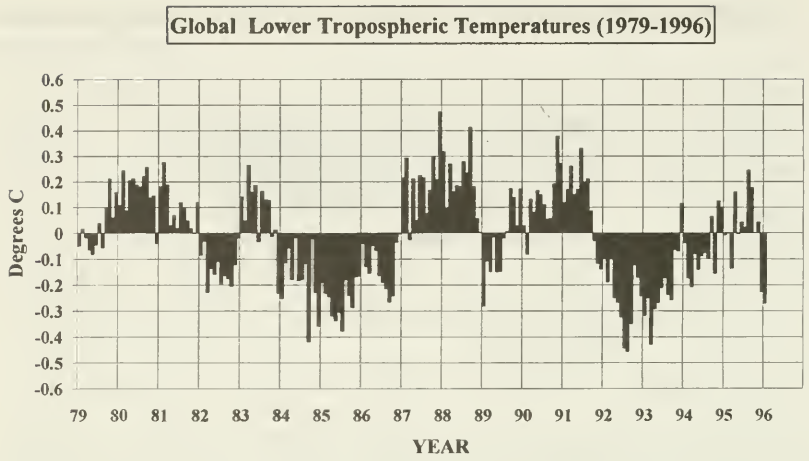
Figure 1. Independent Validation of MSU Temperatures



Two different satellites can observe the earth with independent MSU instruments. This graph shows the "signal" of temperature variation (upper curve) as the average daily temperature anomaly measured by two satellites, NOAA-10 and NOAA-11, over a two year period. The "noise" of the measurement is the difference in temperatures determined by the satellites (lower curve). Notice that the temperature varies substantially from day-to-day and week-to-week, but that the difference is almost non-existent. The shows that MSU instruments are very precise.



In places on the earth where balloon measurements are taken, a direct comparison can be made between the balloon temperatures (dashed) and the temperature the satellite measures (solid) at that location. As shown for St. Cloud MN, the agreement is phenomenal (correlation of +0.98).



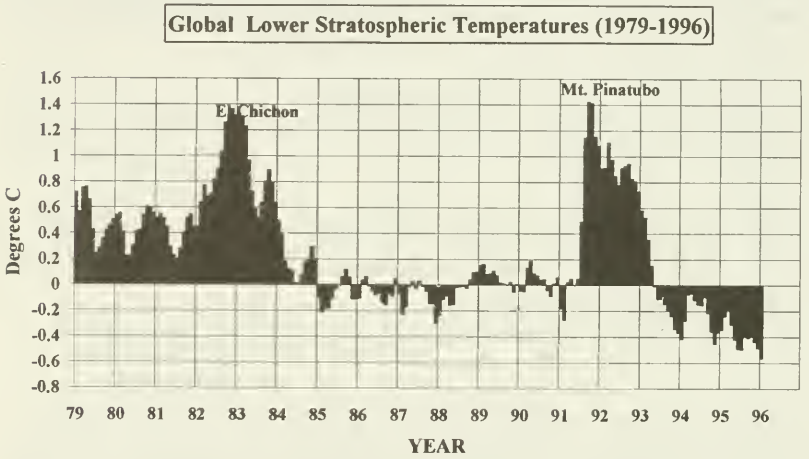


Figure 2. (Top) Seasonally adjusted monthly variations of the global temperature of the lower troposphere (surface to 20,000 ft.) as measured by Microwave Sounding Units. (Bottom) As above but for the lower stratosphere (50,000 to 65,000 feet).

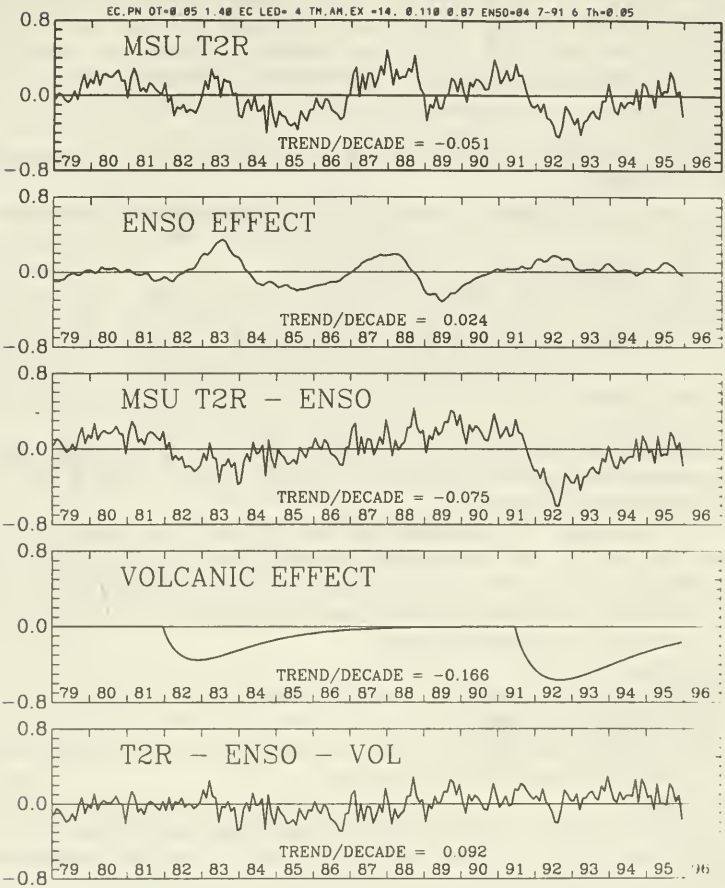

EC.PN OT=0.05 1.40 EC LED= 4 TM.AM.EX =14. 0.110 0.87 ENSO=84 7-91 6 Th=0.05
MSU T2R
TREND/DECADE = -0.051
ENSO EFFECT
TREND/DECADE = 0.024
MSU T2R - ENSO
TREND/DECADE = -0.075
VOLCANIC EFFECT
TREND/DECADE = -0.166
T2R - ENSO - VOL
TREND/DECADE = 0.092
0.8
0.0
-0.8
79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96

Figure 3. (Top). Monthly global average temperature anomalies (as in Fig. 2) for the lower troposphere (°C). (Second) The influence of tropical Pacific temperatures on the global temperature. (Third) The global temperature after the influence of Pacific temperatures has been removed. (Fourth) Influence on global temperature of volcanic events. (Fifth) Global temperature variation once Pacific Ocean and Volcanic effects have been removed.

Mr. BARTLETT. Well, thank you very much. I know our Chairman wanted to return for the questions, so let me ask you all in the interim between now and when he returns if there are any of you who would like to challenge the position or statements of any of the other of you?

Yes, sir?

Dr. MACCRACKEN. Well, I want to try and clarify this issue of scientific consensus.

It is true, as Dr. Davis said, that science doesn't operate that way. Science operates in a very contentious way of arguing and looking for challenges and uncertainties.

But periodically, on issues of public importance, science has to come together in some way to provide information for decision-makers. And the best way we have figured out how to do that is to try and have something like what the IPCC has created, which is to create panels on various questions and then to try and write a report that is encompassing of the range of views.

IPCC does not come up with a single answer. They come up with quite a wide range of answers, actually, because they recognize that there is uncertainty.

So it's important to understand that what a consensus does is the way in which the scientific community is speaking, it's certainly proper to ask for what is going on in the scientific community and what's happening. But the best advice, the collective advice, is coming from assessments.

Thank you.

Dr. MICHAELS. If I could respond to that.

Mr. BARTLETT. Yes, sir.

Dr. MICHAELS. Thank you. I'm not on mike, but I've heard that I'm loud enough that it doesn't matter.

[Laughter.]

What Mike says is well and good and has merit. But you need to understand the process whereby the scientific consensus is achieved.

If we took 100 scientists and put them in a room and asked them their opinion about a subject in which in fact the truth was not known, I assure you that the consensus that would emerge from that room would be some regression to the mean opinion of the group of scientists.

That would not necessarily be what is truth. Let me give you an example from the Intergovernmental Panel on Climate Change.

In 1990, they produced a report in which they estimated that the temperature between then and the year 2025 would rise by 1.0 degree celsius. That's a third of a degree per decade.

Scientists who reviewed that, like myself, said that this simply can't be correct because the planet is not warming at such a proper rate.

I think I have to stop talking now.

[Laughter.]

Mr. BARTLETT. No, that's fine. I just asked them if any of them wanted to challenge the statement of any of the other of them.

Chairman WALKER. Okay. Very good.

Mr. BARTLETT. And they're responding to that now.

Dr. MICHAELS. Can I finish my statement?

Chairman WALKER. Please do.

Dr. MICHAELS. It's as brief as I can possibly be, which is probably far too long.

And the scientists that made this statement, many of them, including myself, hypothesized that the reason that it wasn't warming up was that something was interfering with the warming that was causing an increase in cloudiness, sulfate aerosol being an example of something that can do this.

Those scientists were not included very much at all in the 1990 consensus.

When we got to 1995, we find out that it is now the consensus that in fact the climate models that were engaged in the 1990 and 1992 processes, 1992 being created specifically for the Rio Earth Summit, were in fact predicting too much warming.

So that the scientists that were marginalized from the consensus in fact turned out to be right.

I would urge that when you look at this problem of scientific consensus, that you not only look at the consensus, but you also look at the detractors or the people who criticize that consensus, who do it in a way that seems internally consistent.

They may in fact turn out to be right.

Chairman WALKER. Is there anybody else who would like to respond to that which they heard in terms of the testimony?

Dr. Lindzen?

Dr. LINDZEN. I don't know. I guess this is on. But in terms of Mike MacCracken's discussion of the IPCC, and I guess Bob Watson, I do think somewhat, not in disagreement with Mike that the IPCC process, however flawed, does have a very wide range of statements.

I would argue that the policy-maker summary and the executive summaries tend to misrepresent this.

But I think the real problem we have at least is these are public documents which are not widely read. One has a great many groups claiming to tell the public what these documents say.

I think that may be a more serious issue than what they actually say. We've had several ads for the Union of Concerned Scientists say, don't believe anyone who disagrees with the catastrophic scenario. Believe us. We represent the IPCC.

I don't think that there was anything in the procedure that suggested that they were the representatives of the IPCC.

Chairman WALKER. Well, at least, I would say to you, you were only called junk scientists by them. We've been referred to as potted plants.

[Laughter.]

Dr. LINDZEN. Yes, that's right.

Chairman WALKER. Dr. MacCracken?

Dr. MACCRACKEN. Mr. Chairman, one of the things that we have worked very hard on this year, as the government has reviewed the IPCC process, has been to be exceedingly open with it, to make sure that the documents were widely circulated. We in fact made them available through a Federal Register notice so that people could review the draft.

There was indeed, perhaps, too narrow a perspective taken several years ago. We've learned from that perspective and have opened up the process.

All of the panelists here are in fact listed as contributors to the IPCC report, or in some case authors, and several of them contributed to—at least several of them contributed to the review process.

So we've worked very hard to make IPCC a very open process to try and get the best possible information.

Thank you.

Chairman WALKER. Thank you. Dr. Davis?

Dr. DAVIS. Yes, I'd like to comment on that with a specific example.

I am one of the people who was a contributor to the IPCC report and also had an opportunity to provide my comments on the first draft version.

I was asked to submit a several-page report on climate atmospheric circulation, as I just talked about. Not only in talking about my research, but that of many other scientists, all in the referee literature.

My general view of atmospheric circulation change has been that there is no evidence by looking at that record to indicate that atmospheric circulation has changed in response to increasing concentrations of CO2 and other trace gases.

I got the draft version of the IPCC report back with my chapter and it contained absolutely none of the information that I submitted.

My initial thought was perhaps what I submitted, all of which is in the refereed literature, was not in line with what the authors of that chapter believed to be the scientific consensus, if you will, on that particular issue, or with the goals of that chapter.

In reading the comments, I did however find a number of people who had the opposite view, and some of these publications were not even submitted for peer review in the scientific literature.

This led me to go through the entire IPCC's document and count the number of citations that were either not in the literature, some of which personal communications, things that were to be submitted for publication.

Ladies and gentlemen, this is not how science works. Science works, as we've all said, by continuous review and criticism of other people's works. Some 30 percent of all the citations in the IPCC report were unavailable to me when I was reviewing the document.

That is not a scientific document. It's a public policy document.

I sent these comments back to the IPCC in the hopes that they might change the last draft of the report, and in fact, none of these changes were incorporated.

So I look at the IPCC with significant skepticism.

Chairman WALKER. Dr. Watson?

Dr. WATSON. Thank you, Mr. Chairman.

There's a fundamental rule in the IPCC that we either use peer-reviewed literature or preprints so it can be to be submitted, as long as that data or that preprint is available for review.

Now there is one particular instance where I know there's a problem and that is with Dr. Michaels sitting to my right. So before he says it, I will say it for him.

And that is, he actually requested the output of a General Circulation Model (GCM) from the British office and didn't get it.

Other than that one example where he specifically requested information, I believe that if any reviewer asks for the preprint of any document that is cited in IPCC, it is available. It was certainly true for IPCC working group 2, where I cochaired it, and there's never been a criticism.

There is one other point that I would just like to make for the record.

There seems to be a misunderstanding of who writes the policymaker's summary. Most scientists actually tend to agree that the fundamental scope of the work for IPCC is broad and we do indeed talk about what is known and not known and we actually do quite well describe uncertainties.

A number of people believe that the Summary for Policy-Makers does not accurately reflect the underlying documents. It's actually the lead authors, not the governments, that write these policymaker summaries.

And so these are indeed summaries written by the scientists and then peer-reviewed by both the experts and by the governments themselves. So, indeed, the Summary for Policy-Makers should be viewed as being written by the peer-reviewable community, just like the main text.

Chairman WALKER. What I'm going to do here is, I think this discussion is extremely valuable amongst all of you and is very useful, and I'm going to take some time to allow that to go on a little bit later. But I don't want to keep people from asking questions who are members of the Committee here.

So since Mr. Volkmer has now come in, I'm going to let him ask some questions and some of the other members. And then when we come back here at the end, I think what we'll do is allow that discussion to go on because I think it's very useful for our understanding of how the process works.

Mr. Volkmer?

Mr. VOLKMER. Thank you very much. As I understand, the purpose of this hearing is to basically look at the proposed EOS system with the various satellites and determining whether or not we can do that within the budget and use the scientific and have a scientific base when we get the basic information, et cetera, down.

So what I'm curious about is, Dr. Michaels, do you feel that we should not have the information or would you not need that information——

Dr. MICHAELS. Absolutely not.

Mr. VOLKMER. Pardon?

Dr. MICHAELS. Absolutely not. I think that we should ask a couple of questions over each module. The questions that I would ask are does this particular aspect of the program help increase our understanding of the issue of climate change, particularly with respect to the disparities between projected and observed changes and the second question, which is probably the more difficult question.

Are there other ways to do this that are covered by other programs that are not necessarily this module? And that allows you to rank things.

But I am a believer that the data and scientific observation are what is moving the paradigm on this issue more and more towards moderation.

So put me in support of these things, please.

Mr. VOLKMER. All right. Dr. Lindzen?

Dr. LINDZEN. I think my voice doesn't carry as well.

[Laughter.]

But, in any event, I think you're asking a difficult question, even though it's easy to always say one is in defense of data.

There is no question that, historically, EOS started in an unfocused way, to just take a lot of measurements and expect this would answer and, in fact, ask the questions because the field was in a very inchoate state.

In fact, all through our discussion, there's been a confusion. Of course, satellites, instruments don't answer questions. People answer questions.

If you simply expect a blockbuster approach to taking data, will automatically tell you answers, that's pointless.

At the time EOS began hitting the drawing boards in its first incarnation, one of its leading supporters in the scientific community was Bob Dickinson, who is now in Arizona. And even he said, if he had the data tomorrow, he wouldn't know what to do with it.

So there are many approaches to taking data, but EOS initially was starting with the instruments and hoping the questions would arise. There is a certain utility to this kind of blue-sky approach when a field is in its early stages. But there's also a need, I think, to have some ideas on the books to which an observation provides a specific test. And there's rather little of that in EOS.

Mr. VOLKMER. All right. I'll ask another question in a minute.

Dr. Balling?

Dr. BALLING. I think Dr. Michaels covered many points that I would have covered.

It's inconceivable for me to think about how we could ever generate data in time and space as accurately as we can generate the data from the satellite system.

So there are any number of hypotheses and theories that can be tested with satellite data that could never be tested if we were to use conventional data.

So I'm the biggest supporter you could ever imagine of generating more satellite data bases.

Mr. VOLKMER. Dr. Davis?

Dr. DAVIS. I have really nothing to add to the three previous speakers. I agree with them.

Mr. VOLKMER. All right. Fine. Let me tell you where I'm coming from, as somebody that sits up here making decisions whether to go on or not go on with the program.

And I'm not a scientist. I'm one of those people that says that the professional politician, and before that is a lawyer. And some people say that I've been up here too long, out in my district and all that kind of stuff.

But to me, it's a source of information that I may not be able to get, or you, as scientists, you may not be able to get otherwise. And it could help us in our further understanding of what's happening to our climate.

That's all. I'm not saying it's going to say we have global warming. I'm not going to say it's nonglobal warming or we're going to cool. But I'm saying it's knowledge. To me it's knowledge, or a method of getting knowledge.

Do you agree with that or disagree? Yes, with the satellites and the information that we're eventually going to get from those satellites.

Dr. LINDZEN. It's knowledge. I don't think there's any question about that. But what's fascinating, and in my written testimony I have that, is that, surprisingly, once you focus a question, you often find that we already have information.

So it turned out that, for instance, a military satellite was taking data on water vapor that EOS never was going to take that turned out to be vastly superior.

I don't know how one deals with it in the political realm when there's inevitably an element of serendipitousness, when it isn't an issue of committees planning, when information often is taken that there's no one to look at, that the thing that motivates people to look at it is ideas.

I think the fortunate part in the testimony that I have written is that when the ideas were there, it turned out that we had more information than one might have supposed.

Now EOS may constitute such information at some time, but it was not focused on answering questions.

Chairman WALKER. The time of the gentleman has expired.

Dr. Watson?

Dr. WATSON. Thank you, Mr. Chairman.

While Dick Lindzen is correct to say that the beginnings of EOS were what I would call platform-driven, the question poses, how can we use the polar platforms of the space station?

That rapidly changed. Over the last decade, hundreds of scientists have been involved in posing questions and relating those questions to the types of measurements that can be made from EOS.

In addition, over the last few years, many of us have been involved in looking at the classified assets that this country has to see how we can use those classified assets to complement EOS and the other systems.

So at this moment in time, it is a science-driven program. We're looking at the commercial assets. We're looking at the classified assets and we're looking to see how the nonspace assets of theoretical modelling and ground-based observations will all play together.

Chairman WALKER. Thank you, Mr. Volkmer.

Mr. Tiahrt, questions?

Mr. TIAHRT. I'm not sure I have all this figured out. We've got satellite data that's telling us that it's getting cooler. And we've got ground-based data that says it's getting warmer.

I think there is a value to accumulating data, which you all probably would agree with. Those are the toys that we play with. Hope-

fully, we build something constructive out of it that can have a long-term effect.

But I think when we approach this problem from our perspective, we have to find out what's the most economical means of obtaining the data. Is it through one method or can we—like Dr. Lindzen suggested that occasionally we find a source of data that we weren't aware of or that we weren't even planning on putting into the specifications for EOS, and we find out that it's very valuable.

What options have we not pursued in our program? Have we explored all the data that's available? Or is there some other thing that we're, in our current funding line, that we're excluding by preconceived notions?

Dr. Lindzen?

Dr. LINDZEN. I would like to briefly address that. And I think if there's one resource that we don't have enough of it is essentially the human resource for asking questions.

Now you brought up an interesting issue. There are discrepancies between land-based data and satellite data. Now there are also physical differences. The satellite data is an integral over air, over a certain height, and the surface data is at a certain level.

Now, what I find fascinating about the discussion of this discrepancy that virtually every model I know says that if you have greenhouse warming, it will be as large, upper troposphere, as it is at the ground. It will affect the whole atmosphere, at least the lower ten kilometers. Whereas, things associated with El Nino and ENSO and so on, might just be the surface.

Normally, that discrepancy would be at least considered as a means for distinguishing two processes. Instead, we're acting as though surface has a priority, whereas, the theory, the modelling results would tell you, if it occurs at the surface and not in the satellite, a priori, it's probably not greenhouse warming.

The absence of that thinking and focus and so on, is perhaps the leading cause of waste in an economy in the use of the data we have.

Mr. TIAHRT. Dr. Michaels?

Dr. MICHAELS. I agree with Dr. Lindzen wholeheartedly. I would just for the record like to make the hypothesis, which I have never made on the Congressional record, that we will find ultimately that the reason the planet did not warm as much as it was supposed to will be in large part because of miscalculation of the vertical distribution of heat in the atmosphere, and the satellites will be found to have been the Rosetta Stone that created this new synthesis.

Mr. TIAHRT. Dr. MacCracken?

Dr. MACCRACKEN. I think first I'd like to echo the comment that Dr. Lindzen made that the measurements of the atmospheric temperature and of the surface temperature are different quantities.

This new measurement that has been made over the past 15 years is prompting a lot of new studies to try and understand that. And we're starting to understand a number of the reasons why they are different and why they should be different and how consistent or inconsistent they are.

So there's a great deal to be learned.

The first part of your question was are we measuring sort of efficiently or effectively, and how about satellites?

There are certainly programs that want to put buoys in the ocean. A lot of oceanographers would like to have that, and there are some things that that has been a great assistance in helping us improve seasonal to interannual forecasting in the Pacific and it may—well, in the tropics, and by putting more into the Pacific Ocean, it may help better predict the climatic anomalies we have year to year.

That's not climatic change, but just the variations that we have year to year.

We certainly need surface networks. The difficulty with that compared to satellites is each country has to do it and there are none over the ocean and it's very hard to get a self-consistent set.

And what satellites provide is global coverage, a consistent set with exactly the same instruments so we don't have to make all these adjustments and biases. We have to still make some, perhaps, but not locally.

So there's just a tremendous amount of information that can come out of the satellite record. And the 24 sets of information that NASA's talking about provide benefits to all of the different aspects of the program. They're not all for climate change. Some help in other areas as well.

Mr. TIAHRT. Let me ask you this question because I think, certainly through some of the comments that have been made, for example, the Vice President, he has a preconceived set of notions about what's happening on the face of the Earth environmentally.

Are we, through the 24 different categories or whatever the specs call out for now, trying to establish a preconceived set of notions? Or is this approach going to be open enough that we can react to new data and perhaps, like the discrepancies that we're talking about now, maybe being the Rosetta Stone. Is it open enough that we can react to new data?

Dr. MACCRACKEN. Certainly. The measurements from space have no preconceived notion about what they're going to show. Their measurements have temperature or water vapor or——

Mr. TIAHRT. No. I mean the categories that we're using for specifications, the 24 categories.

Is that too limiting or is it not limited enough?

Dr. MACCRACKEN. Well, scientists would always like to measure more. This restructuring, I guess, of EOS has led to a narrowing of the kinds of categories.

But the ones that are there are deemed as the most vital and are just fundamental to trying to understand what's happening in the atmosphere.

And then the scientists are the ones responsible for trying to put together the IPCC report with governments asking questions and outside experts asking questions.

We had many interesting comments on the draft IPCC report from industry, for example, that the U.S. incorporated in its response in passing those forward.

Chairman WALKER. The time of the gentleman has expired.

Mr. TIAHRT. Mr. Chairman, I would like to say, Dr. Watson, I presume.

[Laughter.]

Dr. WATSON. Correct.

[Laughter.]

While the Vice President may or may not have——

Chairman WALKER. We'll hope that that wasn't put on the record.

[Laughter.]

Dr. WATSON. While the Vice President may or may not have a preconceived idea, most of his ideas do come from the international science assessments.

But independent of that, the NASA data policy and approach I think answers your question. All scientists, independent of whether they do or do not believe in global warming, whether in the mainstream or viewed as skeptics, will have complete and utter access to that data to interpret it in any way they want.

The 24 sets of measurements actually were put together as the highest possible set by a very, very wide range of scientists, again, some who may be viewed as skeptics, some who may not.

I think, indeed, what we're talking about, as you say, you're confused. We all are. Why is the satellite data different from the ground-based data?

This type of research program, observations coupled with theory coupled with modelling and other expertise, will provide the answer to this.

The comment I would just make is you heard a lot today about what you can and cannot derive from a 15-year data record. I believe a 15-year data record is just way too short to make any real deductions about whether the Earth is or is not warming. You have natural cycles of change in the Earth's system that warm or cool over 15 years.

And so making these deductions that the models are either right or wrong over a 15-year period is actually the wrong way to go.

Chairman WALKER. Ms. Rivers?

Ms. RIVERS. Thank you, Mr. Chairman. I have a couple of questions. I want to go on a different tack because I want to understand something that I've been hearing over several hearings that we've had.

And that is the whole issue of the lack of integrity within science in general and particularly, when it's being funded with federal dollars. And so I want to speak directly to Mr. Michaels, Mr. Lindzen, and Mr. Balling, in particular.

Is it your argument that current science that is being funded through federal dollars somehow lacks integrity?

Dr. MICHAELS. I take it you're referring to my testimony.

Ms. RIVERS. Both today and previously. I apologize for having to be in and out today.

Dr. MICHAELS. It's nice to see you again, by the way.

What I wrote in my testimony today I think is true. It says, in the area of global climate change, there is little doubt that several public servants feel strongly that research indicates the, quote, dangerous view of climate change is more likely than the, quote, moderate synthesis.

I think you know to whom we are referring.

Thus, the federal research presence in this area will always raise suspicions, real or imagined, that the funding process has become politicized.

I believe that that statement is a truism and there is nothing that we can do about it.

Ms. RIVERS. But haven't you also in the past been hostile to people who have asked about funding for skeptics, where their money has come from and how they might be biased by their dollars, where their dollars originate?

Dr. MICHAELS. I would like you to cite specific chapter and verse, if you could.

Ms. RIVERS. Well, specifically, and I'll point to all three because I read it in a variety of things, that somehow there is an illegitimacy currently for scientists who are operating with federal dollars because of preconceived outcomes or views they might be operating on——

Dr. MICHAELS. I don't believe I've ever written or said that, Congresswoman.

Ms. RIVERS. Good. Then I will go to Lindzen and Balling, particularly.

Dr. BALLING. You raise an interesting point here. But, fortunately, in science, we have what I call a sanitizing process. Whether the Federal Government funds research in Tempe, Arizona or a coal association funds research in Arizona, when we're done with the project, we must submit the article for peer review. And the peer review process that Bob Davis spoke of earlier, I believe really sanitizes all the research.

Irrespective of who funds the research, I must get that approved by my peers before it's published.

So if I come here today and base my testimony on published research, who funded it becomes somewhat irrelevant.

Ms. RIVERS. So why does this theme keep coming up over and over that there is—and I'm using my words here—that there's kind of this global conspiracy of people who are coming up with one particular point of view and somehow keeping skeptics and folks who have another point of view out of the mainstream scientific community or out of their ability to publish or get funded or these sorts of things?

Dr. MICHAELS. I don't think it has to do with you and I don't think it has to do with me. I think it has to do with things that are completely beyond our control and inevitable.

And I would ask you, if you would, to switch roles with me. I will let you be the head or the near-head of an agency who has come here and been asked to testify. I will be—I'll be a senator.

[Laughter.]

Ms. RIVERS. I feel so sorry for you.

Dr. MICHAELS. Just to keep it nice.

[Laughter.]

We have about $2.2 billion available for research on global climate change. Do you think that your agency merits this? Do you think that it is an issue so important that we should spend all this funding on it?

What's your answer? Heck, yes, because if you didn't say yes, your colleagues who are sitting in back of you in this room would have thrown the knives at you before you got out the door.

Ms. RIVERS. So is that what you mean when you said that you thought scientists were required to shill for the apocalypse?

Dr. MICHAELS. What I am saying is—no. What I am saying is that the funding process guarantees that people will emphasize that this is an exceedingly important problem and that is often misinterpreted as believing in the apocalyptic notion.

Ms. RIVERS. And do you think it is equally possible for people who are being funded by industry interests to present their data in such a way as to suggest that the industry—in an outcome that would favor their industry?

Dr. MICHAELS. I agree with Bob Balling. When you go into the scientific literature and you have a review process, and that review process is a remarkable sanitizing agent in the long run.

Ms. RIVERS. So that, ultimately, it outweighs one another and there's really no problem. We can just all go on——

Dr. MICHAELS. In the longest run, the truth will come out.

Ms. RIVERS. So we should just all go on collecting data, analyzing data, and arguing our points of view out in the scientific arena?

Dr. MICHAELS. I hope so.

Chairman WALKER. Time of the gentlelady has expired.

Mr. Lindzen had a comment.

Dr. LINDZEN. I just wanted to say, you mentioned that, without citing anything specifically.

As somebody who has never received industry support for research, I suppose the fact of the matter is I stand as evidence that government support does not, per se, determine the nature of the position.

But I think all I've said in my testimony is that there are several issues. First, there is a deep issue of scientific integrity that it should focus on disproof.

That's essential to it.

And so, for instance, consensus documents are intrinsicly political and not scientific because the role of science is to challenge.

Now, for example, there was a document, the Forum Report of the U.S. Global Change Research Panel, where Pat and I were invited at the last moment because it was supposedly a response to Representative Dingell.

We were arguing. We were saying, here's what has to be challenged. Here's what has to be tested, and so on.

All of a sudden, a document emerges that had nothing to do with the discussion and we were listed as part of the consensus. That's inappropriate. That's designed.

Ms. RIVERS. In any area.

Dr. LINDZEN. That's right. That sort of thing is going on, and I think it indicates a problem. And the problem is the concern over funding, whether it's from industry or from other things.

I agree with Pat. There's a natural tendency to say the problem is serious, that you'll find much less statement from the scientific community that we expect warming. But there's a feeling you should at least say, it's serious.

Now, that's fine. Maybe it is, maybe it isn't. But this gets worse and worse when you start getting to the business of physicians concerned with the health implications of warming.

Now they are going to have no knowledge of the science of warming, but they're going to have an interest in saying, warming is a serious possibility.

You have economists, my friend, Bill Nordhaus, who really doesn't understand the physics of climate. He's an economist. But he'll get up and say he finds the science of warming compelling.

That's a natural tendency.

Ms. RIVERS. We had an economist here who explained to us his view why global warming was good. So we have economists playing on both sides, where they shouldn't be.

Dr. LINDZEN. Yes, but they'll all say it's a serious issue, because otherwise, why are they doing the economics of it?

Chairman WALKER. The time of the gentlelady has expired.

Ms. RIVERS. Thank you.

Chairman WALKER. Ms. Cubin?

Ms. CUBIN. Thank you, Mr. Chairman.

I would like to ask Dr. Watson, did you test your models against the climate record before the Rio Treaty was signed in 1992? And if so, what was the result?

Dr. WATSON. Yes. Obviously, none of them are my models. All the models discussed in IPCC are from scientists around the world, many of them being U.S. models, others being from Germany, United Kingdom, Canada and Japan, primarily.

Indeed, one tried to test the models and one indeed found, just as today, there are many things that the models are actually in agreement with the observations and there's many places where there are disagreements.

One can say, is the glass half-full or is the glass half-empty. One can decide to stress those areas where there is agreement or those areas where there is disagreement.

I believe the IPCC in the 1990 report and in the 1992 report quite carefully showed where there was agreement and showed where there were problems.

As Pat Michaels said, it was quite clear in 1990 that the models were overestimating the observed change to date. That's why the first chapter in 1990, chaired by myself, was on aerosols.

The aerosols at that time had not been put into the models. But we realized that this was potentially a source of cooling. And so there was a thorough chapter discussing possibly the direct radiative role of aerosols and indirect.

By 1992 to 1995, these efforts were now being put into the models. And so, at that particular time also, we knew that the models were only the so-called equilibrium models—what happened if you suddenly changed CO2 from one state to another?

In that early document, we also started to look at the implications of a gradual change in CO2.

So the point is, the answer, yes, one looked at the observations. One looked at the models. And one, I think, quite fairly described where they're in agreement and where they disagreed.

Ms. CUBIN. Would anybody else like—oh, sure. Go ahead, Dr. Michaels.

Dr. MICHAELS. If I could respond to that. And here is the policymaker's summary from 1990.

The average rate of increase of global mean temperature will likely result in an increase in mean temperature of 1.0 degrees C above the present value—that's 1990—by 2025.

I don't think that—I really do not believe that the consensus of scientists in 1990 would have been that the planet would warm one degree in 30 years.

More importantly, to answer your question, this is the 1992 report—can you find a graph in this report that compares the transient climate model output, which is really the guiding model in this report, to the hemisphere temperature behavior?

The answer is no.

I have been mystified for a long, long time as to why that test was not performed at that time.

Ms. CUBIN. Would anyone else on the panel like to respond?

Well, I don't really want a debate. Let me go on.

Chairman WALKER. Well, but I believe the dialogue is helpful here.

Ms. CUBIN. Okay.

Chairman WALKER. If you have more questions to go forward—but Dr. Watson's response is valuable, I think.

Ms. CUBIN. Well, I do have a few more questions.

Chairman WALKER. Okay. Well, then, why don't you go ahead.

Ms. CUBIN. If you'll just give me some more time.

Chairman WALKER. Why don't you go ahead with your questions and we'll come back to this.

Ms. CUBIN. If you just give me—I only have four questions total. So go ahead and let him do it and then I'll ask my other three.

Chairman WALKER. Do you want to respond, Dr. Watson?

Dr. WATSON. I believe one of the reasons that that indicated simulation was not carried out, the comparison of the transient model with the data, was one of the problems that many of these transient models were dealing with was the so-called cold start. And the question was how to initialize the model in order to try to compare to the theory?

That's something that's evolved. Science is evolving. By 1995, we're now starting to compare the observations with the model outputs. This is a part of the normal evolution process of science.

Chairman WALKER. All right. Ms. Cubin?

Ms. CUBIN. Thank you. Dr. Michaels, would you have thought—I'm a chemist. So I realize how there is evolution in science and how things do change.

But would you have thought in '92 that that test should have been run?

Dr. MICHAELS. Absolutely. In fact, as early as 1987, TML Wigley published a paper in the journal, Climate Monitor, in which he was using the earlier types of climate models, more of the ones that went into IPCC 1990. And he said that the planetary warming should have been about 1 to 1-1/2 degrees Celsius. This is up to the mid-1980s.

Somehow, that statement never ever appeared in any consensus document in 1990.

In 1995, eight years later, JFB Mitchell publishes a paper in the Journal of Climate in which he says that the minimum warming that should have been observed by the transient coupled ocean atmosphere models without sulfates was 1.3 degrees and the maximum of 2.3.

That's an error of between 160 and 360 percent.

This has been known to this community. I have reviews of papers submitted in 1993 to Science magazine where I point the disparity out and it says, the community is well aware of this disparity, so there's no need to publish this paper.

And yet, we come to this hearing and all of a sudden, it's news. I don't understand this.

Dr. BALLING. I don't want to give you the impression that in the climate community, there are the modelers and the data-driven scientists and there's no interaction between the two until two weeks ago.

The reality is that, even in 1990, the IPCC has scientists who are looking at global records and commenting about the warming that they're seeing relative to the warming that should be observed in the models, or would have been predicted by the models.

So, at a very simple level, there are people in the 1990 reports comparing model outputs to observations. But it's a lot tougher than saying, well, is there a link between global temperature and the global temperature for the models, because then you get into the issue of where does the warming occur spatially?

We begin to look at latitudinal distributions. And then we can turn our attention into the vertical and say, the model is giving us predictions about what we should observe in various parts of the atmosphere.

So to test a model against observations is far more difficult than to say, here is a plot of planetary temperature and here is what the model predicts for planetary temperature.

That's only the beginning of the test and these have been going on for decades.

Ms. CUBIN. Does anyone on the panel agree with Dr. Watson's statement that "the scientists of the world have agreed that climate is changing and that there is a discernible human influence"?

Chairman WALKER. Your time has expired. I'm going to let the question be answered.

Ms. CUBIN. Thank you.

Dr. LINDZEN. May I say something about it? I think that statement—I will say that everyone logically has to agree with that statement because that statement says absolutely nothing. It puts no quantity on it.

Now if somebody asked me, CO2 has gone up 30 percent. Will this have an effect on climate? I can say, yes, if they're silly enough to ask that question. It could have been 2/1000ths of a degree, but it should have some impact.

That is exactly the kind of obfuscation that prevents any meaningful display of information.

Ms. CUBIN. Especially to laymen.

Dr. MICHAELS. Well, in defense of Dr. Watson, in 1986, he testified—and I forget which hearing it was at. And when he was asked

about global warming, he said, it's only a matter of magnitude and time.

Dr. MACCRACKEN. If I may. Having been there and worked on the statement, let me say, the quantitative information is in the report. It's in the chapter. It talks in detail about how that word was developed, discernible. I mean, how the results were developed.

There are some things to realize.

We are in the warmest decade, the warmest few decades that it has been in at least 1400 years, and possibly back much further than that, depending on how you reconstruct the records.

The trendline is upward. There isn't any disagreement on that. The patterns that are occurring look very much like the CO2 plus sulfate plus ozone limit are occurring.

So you're seeing a whole bunch of coincidences of events, perhaps, or you might argue they're coincidence, but they're what we are expecting in very interesting ways. Discernible means that you can see it above the noise.

That's what it means. You can discern it and see it as something different. And that was our way of trying to choose a word at 12:30 in the morning, or something like that, whenever the meeting was going on, that tried to convey that to the general public without providing precise numbers.

Chairman WALKER. The time of the gentlelady has expired.

What I want to do is get back. We were getting a pretty good dialogue amongst the people on the panel earlier.

Dr. MacCracken, what stuns me is, somebody who's a nonscientist and so on, whose data are we relying on from the year 500 B.C.?

Dr. MACCRACKEN. One of the great fun things about science is how to reconstruct the past climate and try and learn from that.

That information comes primarily from tree rings. It comes from understanding—you can develop relationships between how much tree rings grow, depending on the weather. You do that around the world and you try and get a good estimate of that.

Chairman WALKER. But it's a somewhat different data set than what we're relying on for some of what we're doing now.

Dr. MACCRACKEN. It's actually calibrated quite well and actually fits together quite well.

Chairman WALKER. Dr. Christy?

Dr. CHRISTY. Yes. I was on the group that wrote that statement. We were looking at glacial extent, primarily was one of the data sets, besides the tree rings and other proxy data like that.

Chairman WALKER. That's useful, thanks.

Dr. Michaels?

Dr. MICHAELS. I have the chart that Mike was referring to. I hope that I can get away without dragging the microphone over here.

I'd like to point something out. This is a positive tree-ring target in the northern hemisphere temperature. The large rise is between 1910 and 1920, long before the greenhouse effect could have done it.

So I think we have to be very, very careful about mixing that.

Chairman WALKER. Okay. Dr. MacCracken, as I say, what I'd like to do is get a dialogue going amongst the participants here because I think that's useful for us.

Mr. VOLKMER. Mr. Chairman? Mr. Chairman, before we continue on, I'm going to sit through this hearing. To be honest with you, I don't see how much of this has to do with whether the IPCC report was valid, invalid or anything else, compared to what we're going to do about the satellite system.

Chairman WALKER. Well, Mr. Volkmer, when this hearing was chartered, it was chartered for two purposes.

We had a panel earlier today to talk about EOS and the status of that. This is also supposed to be a hearing on the state of the current or the status of the current knowledge about the climate program. That's what we're engaged in on this panel.

Mr. VOLKMER. Well, there's disagreement, undoubtedly, throughout the whole community of scientists about not only the climate program, but what's happening to the climate.

Am I right, Dr. Michaels?

Dr. MICHAELS. I'll buy that.

Mr. VOLKMER. Yes, you'll buy that. So we're just going to sit here and talk about it? Now what has that to do—I'd like to ask the Chairman, what has that to do with whether or not we continue on with the program for satellite observation and the data from that?

Chairman WALKER. Sometimes, Mr. Volkmer, I think it's useful for a committee to have some understanding about what's going on in the fields that they are in fact spending billions of dollars on.

And in particular, I think to have a dialogue which is focused on the intellectual ferment that is going on within this field is in fact a valuable contribution to the understanding of this Committee.

You can choose to sit through it or not sit through it. That's up to you. But I happen to think—I'm learning something.

Mr. VOLKMER. Does the Chairman mean to tell me that he didn't know there was a diversity of opinion within the scientific community about the IPCC report?

Chairman WALKER. Well, obviously, I knew that there was a difference of opinion. I think, however, that——

Mr. VOLKMER. You didn't know the basis for it?

Chairman WALKER. Sure. But I think it's useful to have experts who come in and actually inform us.

It's a little like going to school. You do in fact understand sometimes how things are done. You understand, for instance, the theory behind playing basketball. It sometimes helps to talk to the experts about how you do it well enough to really understand the game.

Mr. VOLKMER. Well, my last comment would be, one of the members on your side implied that maybe the Vice President had something to do with this.

I want to point out to the Chairman and to the rest of you that in 1990, Al Gore was a United States Senator. He wasn't the Vice President. In 1992, he was still a senator and not the Vice President.

I think that was a little cheap shot by the gentleman on your side.

Chairman WALKER. Well, I don't. I in fact made reference, I hope in a lighthearted fashion, to the fact that the Vice President the other day referred to this entire Committee as potted plants.

I think maybe the Vice President has engaged in it in an appropriate political dialogue with regard to these matters, too.

But I think today, whether Mr. Volkmer agrees or not, I think the dialogue here is useful to the Committee's learning experience and I'm going to allow it to continue.

And Dr. MacCracken, I will go to you.

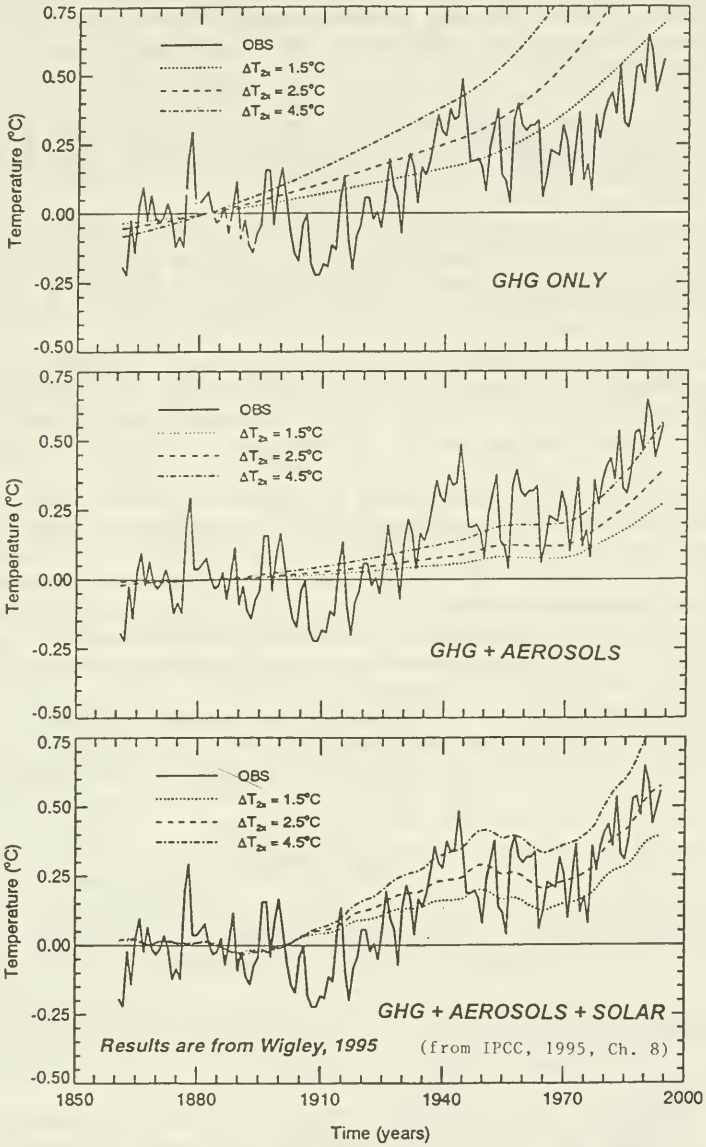
Dr. MACCRACKEN. Thank you very much.

One of the great challenges, as I said, is trying to understand why things are happening. And so, you want to do the empirical investigations that are done, the analysis of data that we've heard about, but you also want to try and reconcile that with a theory.

One of the things—if you put up the next diagram—is to try and indicate where we are and understand where we are.

[The diagram referred to follows:]

HOW WELL DO MODELLED AND OBSERVED CHANGES IN GLOBAL-MEAN TEMPERATURE COMPARE FOR DIFFERENT FORCINGS AND SENSITIVITIES?



(from IPCC, 1995, Ch. 8)

It's a little hard to see, but the top diagram, this wavy line is observations. The observations go up and down from year to year. There are volcanos, there are El Nino events.

The long-term trend of that wavy line is going upward.

The three lines in the top diagram show what would have been this attempted match in 1990, when one was considering only CO2 and greenhouse gases.

And you can see as you get over to the right-hand side of the diagram, there is some disagreement. There isn't a perfectly good fit.

One of the things to correct, though, and what Dr. Michaels was saying, is that there is some warming that occurs early in the record as a result of even the CO2 effect.

As you add in aerosols, which is something that we were just becoming able to do this past year, you start to see it brings the record down. Aerosols create a cooling influence. There's a number of uncertainties. We're not exactly sure how much it brings it down.

If you start adding solar effects, natural solar radiation, which is a measurement that's made from satellites and that we need to sustain, it tries to take it—it's warm in certain periods and it's a little bit cooler in other periods. That starts to bring it into agreement.

Those curves are certainly not in perfect agreement. There is some real departure from them early this century in the period that Dr. Michaels was talking about.

During that period, there were some very large volcanic eruptions that led to some cooling. The question is can we try and explain all of these things? Can we try and understand if there is consistency or large inconsistency by going through these analyses?

Chairman WALKER. Dr. Michaels?

Dr. MICHAELS. Mike, what journal is the bottom result in?

Dr. MACCRACKEN. This has been done since the IPCC, I believe.

Dr. MICHAELS. Has it been published in a journal? Refereed?

Dr. MACCRACKEN. I don't believe it's in there yet, but I'm not quite sure with respect to Dr. Wigley's analysis.

The model certainly has been. The solar flux is from an established journal, one, and this is a simulation based on that.

Dr. MICHAELS. That's all right. There's one thing I want to get back to you on because we've worked together and I enjoy your criticism and your comments, even though sometimes it seems like I don't.

The previous graph, which was the composite tree ring graph for the northern hemisphere summer temperature, again points out that the warming occurs prior to most of the change in the greenhouse gas.

Now, Mike, you were the chair of the U.S. review committee for the IPCC. How many times did I write in my review that it was encumbent upon the IPCC to state that the largest warming in that record occurred before there was very much of a change in the greenhouse effect?

And why was that comment never ever included in the 1995 report?

Dr. MACCRACKEN. I think if you look at the curve, there's warming at several periods. There is indeed some warming that occurs

before 1940. There have been shifts in the climate. And Dr. Michaels often points not only to the shift in the 1920s, but also in the 1970s.

The long term—if you start out at a modest temperature, at the start of the curve where it's sort of normalized near zero, you get volcanic eruptions that exert a strong cooling influence and then you get a recovery from that, you're going to get a warming influence.

And on top of that, with the solar working, you have a chance to get some large changes in that. You're going to get these variations.

Chairman WALKER. Dr. Lindzen?

Dr. LINDZEN. I think, Mike, you're giving a perfect example of just how science ought not be done.

You see the middle curve there on aerosols that's been referred to? We don't have a record of aerosols during that period. We developed a scenario for aerosols that would help this fit better.

It doesn't do a great job once you realize that's the case.

Mike MacCracken talks about the period to 1940 and relates it to volcanoes.

You do realize that after 1912, when Katmai erupted, there was an almost unique period of no volcanoes. And indeed, the only calculations one has says that if you had a very sensitive climate, it should have remained cool until 1940, due to the large number of volcanoes between Krakatoa and Katmai.

But, instead, there was a rapid rise in temperature.

And I think relating that to volcanos is just borderline absurd. It's a good example of where one is trying to defend a picture rather than develop a well-focused test.

Chairman WALKER. Dr. Balling, you were seeking recognition.

Dr. BALLING. Mr. Chairman, I once wrote a book entitled, "The Heated Debate." I think after today, there will be a second edition forthcoming.

[Laughter.]

What I see on the diagram really shows us where the debate can launch at any point.

Dr. MacCracken is showing a graph and a great deal of the agreement that we see between the models and this observed temperature rise occurs in the most recent two decades.

And if I were to look at the end of the table and ask Dr. Christy to plot his satellite record at the tail-end of what we see on these charts, you'd see no agreement whatsoever.

Ultimately, we get back to whose data set are we going to believe in if we're looking for this warming in the most recent few decades.

Chairman WALKER. And in all honesty, that's where we come back to the whole EOS matter, is this whole business of then the data sets that are going to help us understand the realities of all of this because when, in fact, what I'm hearing from all of you is that more data is better than no data.

But I'm also hearing from this panel that it's also important to interpret that data, to have a variety of people who are able to interpret the data.

And I must admit that one of the concerns that I have is that we seem to be making an awful lot of investment in the hardware and all of that and not a lot in the appropriate interpretations.

For example, it's my understanding that in '95, and Dr. MacCracken, you might be able to help me on this, that in the '95 budget, that we had about 30 percent for process studies and about 60 percent for observations and data management.

Which means that in terms of the way in which the programs are structured, that we are devoting only less than a third of the budget to dealing with the data.

I'm also concerned that about nine percent of the total NASA budget on Mission to Planet Earth is actually devoted to process studies, whereas, 91 percent of the money is devoted to other things.

That's where we end up with a concern when there is this kind of contention within the community about exactly what the data set is that you're going to begin from.

I appreciate your comment.

Dr. MACCRACKEN. Well, you're correct with respect to the budget statements. We have to maintain a balance of observational programs, which require some directed kinds of activities and the U.S. global change program, as a whole, depends on NASA to a great extent to augment the ongoing observations that are going on for weather forecasting and other purposes.

And so, I guess one of the——

Chairman WALKER. So if you can reduce the cost of the technology, you can in fact devote more of the money to the actual study.

Dr. MACCRACKEN. Certainly. If we can get the same measurements for less, we'd be delighted to do that and we're pleased to see that NASA is working in that direction.

Chairman WALKER. That's one of the things that this earlier hearing was about. One of the things that we're concerned about is that, for instance, there was DOE information as early as 1991, that indicated that they could have given us the same data collection in a different way at $370 million, instead of the $1.2 billion that we're spending on just one satellite.

Now the question is whether or not they were prepared to do that in 1991. I'm not certain that anybody could have made that judgment.

But we now know, based upon some work that has been done at Stennis and some other places, that there may well be a small sat component.

And so when we decide that we're going to go ahead and buy a couple of big new systems—namely, CHEM-1 and PM-1—we may in fact be investing money in technology that we could get in a different kind of way, in a better way with newer technologies.

That's the question that this Committee is raising, not the question of whether or not there ought to be an appropriate data stream and whether or not it ought to be broadly based. But whether or not the kinds of policy judgments we're making relative to this debate in fact contribute to it in the end or are a hindrance to getting what we need.

Sure, go ahead and follow up.

Dr. MACCRACKEN. If I may just comment on EOS.

I came to this position in 1993 from Livermore, and I was at the 1991 presentation that went on. There was a very active discussion that took place at that presentation and it reflects the comments that Dr. Kennel was making this morning.

And that is, what science needs, especially when we're looking at these relatively small changes, is very stable instruments and very good calibration. We are looking at changes of tenths of a percent or hundredths of a percent to try and get that.

The solar variation, for example, is only about a tenth of a percent. Making any measurement to a tenth of a percent, much less having it go on for five years in space, calibrated, is very difficult.

So that was really the issue. And the question was is there a way to try and demonstrate that all of those things can be done?

It's important to proceed judiciously and aggressively to get information. We're not going to be able to resolve a lot of these questions until we have the information and they made a major effort to get that and get the current hardware up.

This review of EOS is looking at the follow-on instruments. It's a very good question you raise.

The trouble from the scientific community that we have is, if you go from one instrument to another instrument and change them every few years, we have to work very hard to try and intercalibrate between them.

We need overlapping times for an extended period of time. And that means that you have to have more operations going on interpreting these results. You can't just say, oh, well, a new one came along and I'll just switch to that because it might be off by even a tenth of a percent and you will see a trend that is not real.

Chairman WALKER. That's a valid point and it's a reason why, against some of our judgment, we've decided to fly the new Landsat, despite the fact that we think that it's pretty outdated technology.

Dr. MACCRACKEN. I mean, it would be nice to put this miniature technology on with these other instruments one round to try and see how it's going. And we certainly encourage that and I'm encouraged that NASA's looking at that, and Mr. Goldin is looking at that.

Chairman WALKER. Okay. Well, as I say, it's an important discussion because, essentially, it is a question of what we can afford to do to get the right kind of data and do it right.

And the reason why I think that this debate is important is because I think it's important for this Committee to understand that these questions do exist within the science community and that the resolution of the questions is important for us in terms of what we decide is the right policy in terms of what we buy.

I can't think that there's anything more important to this Committee to understand than the fact that there is not a total consensus on all this, that people who tell us that there is a total consensus and don't understand the questions, then probably don't understand the nature of some of what we have to determine.

Yes, Dr. MacCracken?

Dr. MACCRACKEN. In the nature of Dr. Michaels' comment earlier about asking a question and posing it to the panel, one of the chal-

lenges of the global change program is to try and understand what is happening. Science is going to go on in that way.

At some point, we want to find a way to convey information to those who are sponsoring it on these very important questions. And we're struggling with a mechanism for doing that.

We discovered that in the IPCC process. The Working Group I report on how climate is changing is arguing about whether our levels of confidence are up at 90 or 95 percent, or 80 percent, and we're working hard on statistical tests.

When you get to the other working groups, or the economics, as there was a question posed, I think, about economic models, the levels of certainty are much less.

We have to find a way of communicating across from the scientific community, its contention and discussion, across to help provide some evaluated information.

We're looking for the best way to do that and we're certainly willing to explore ways and we'd welcome your suggestions in that regard.

Chairman WALKER. Well, and of course, the concern for those of us as policy-makers is that sometimes, based upon incomplete research, where there are still questions, we're being asked to make policy judgments.

For instance, we're asked to make regulatory judgments. We're asked to make very consequential judgments on something that we find where the consensus is marginal at best.

So you're right. That communication is important.

I've got a couple here—Dr. Michaels, you've been wanting to say something, and then I'll come to you, too, Dr. Watson.

Dr. MICHAELS. I just have to get back to this point because it shows the problems with trying to impose consensus.

Again, the assertion that the current climate is the warmest it's been since the year 1400 is based upon the tree ring record that was displayed on the screen there, and it is a fact that rise in temperature in that record, the largest rise occurs roughly between 1920 and 1930, before the greenhouse effect could have changed much, and it actually falls off a little bit after that.

Now, if there was a statement in the IPCC document that said, the warming in this record occurred before the greenhouse effect had changed very much, that would dramatically change the debate on this issue.

I cannot yet understand, and I have not been given the answer as to why that statement was not in there.

And furthermore, it seems to me that this points out another problem with consensus. Maybe I'm the only guy that noticed it. I don't know. If I was, no matter how many times I wrote it, it wouldn't be a matter of the consensus.

But, nonetheless, Congressman, it was real. Thank you.

Chairman WALKER. Dr. Watson?

Dr. WATSON. Thank you, Mr. Chairman.

Your point that we need a balance between observational programs and theoretical programs is absolutely essential.

I think the Administration, just like you and your Committee, would like to get the cost of the EOS as low as possible so we can

have a balanced program between the space-based observations, in situ observations, the laboratory studies, and theory.

So I think we're all moving in the same direction. We all have the same goals. And that is, a viable U.S. global change program to move our understanding of climate forward.

The point was that in the early 1990s, it was a major move to try and get new technologies. Ed Frieman, as you know, chaired the panel previous to the one under the NAS Board of Sustained Development.

On that particular panel, which is only about seven people, they had a couple of advocates for Brilliant Pebbles and Star Wars technology.

The view of that panel at that time was that while it would have been nice to have moved in the direction of that technology, it wasn't quite there.

So I think the point is where we are today, that is to say, using what some people might believe are rather large platforms, I think this is indeed where we have to be today, but we must move the new technology as soon as possible.

The argument in the Frieman committee a couple of years ago was that it was the calibration of these sensors that was the most difficult to achieve with these very small Brilliant Pebbles, Star Wars type instrumentation.

So if we can solve the calibration issues with these smaller, lightweight payloads, we will go a long way.

What I noted with interest in the written testimony of Balling, Christy, and Michaels, every one of them asked for continuity of data. Every one of them asked for constancy of calibration.

And in Christy's testimony, he said, the best way to achieve that is having identical instruments fly one after another with an overlap period.

That was actually the original concept of EOS, of course. We recognize that original concept of EOS, it was expensive because they were large instruments. The challenge before us now is how to evolve an EOS payload from large instruments to small ones, absolutely ensuring continuity of data and calibration of data.

And that is, I think, the challenge before all of us.

Chairman WALKER. Dr. Lindzen?

Dr. LINDZEN. I think, however, in all fairness to anyone trying to reach a rational budget, one has to realize that Michaels, Christy, Balling were largely talking about the record they use, which are temperature records.

The utility of the EOS platform for the temperature record will be somewhat limited.

On the other hand, EOS will give very high spectral resolution radiance data, and I think it is true, we don't know what to do with that in some respects.

One of the things, of course, with Mike's data up there in the tree rings, always keep in mind, even if you're not a scientist, any time you see a record without an error bar, be suspicious.

There's no error bar. No measurement is perfect. And 0.2 degrees in tree rings is very little. To make a big fuss over that distinction is pushing the data real, real hard.

Chairman WALKER. Dr. Watson?

Dr. WATSON. Thank you, Mr. Chairman. If I could add one other point.

Dr. Michaels, in his testimony, advocated a larger role for the private sector in funding. I think that would be an excellent idea. I think it's quite essential that we should have the broadest possible range of funding for global change.

I think one excellent example of where there was superb cooperation between industry and the Federal Government was on the stratospheric ozone depletion issue.

In that particular instance, the Federal Government had the largest program, just as it does today in other issues on global change. But the Chemical Manufacturers Association put together a small program, only a couple of million dollars a year. Absolutely vital.

It was an international program. It brought the industry right into the middle so that they, with university scientists, government scientists, could actually hand-in-hand look at some of this scientific information, develop the models, develop the data.

And so if there was a way to encourage the private sector, whether it be industry or whether it be environmental engineers, to have a more enhanced program which we could coordinate with our federal program, that would indeed be the best way so we could all start to look at this information in a much more coordinated manner.

Chairman WALKER. Dr. Michaels?

Dr. MICHAELS. I have to say that that testimony explicitly refers to two groups with considerable resources—industry and the environmental community.

I think it's really important to get both of those stakeholders involved in the basic research process on this issue, especially because your funds are not unlimited.

And I have had experience, direct experience, in a totally different realm, where this has been forced. It's something called the Southern Appalachian Mountain Initiative. I'm the Virginia representative on it.

It includes industry. It includes environmental groups. And it includes government. And it forces people to interact in a way that is ultimately constructive.

Chairman WALKER. Well, with that——

Mr. VOLKMER. Mr. Chairman?

Chairman WALKER. Mr. Volkmer?

Mr. VOLKMER. I'd like to inquire of Dr. MacCracken.

Earlier, there was a discussion about the need for more scientists to be able to participate in this program and the need for—what is it?—DIS. Is that correct, the information system?

Dr. MACCRACKEN. Earth Observing System.

Mr. VOLKMER. Right.

Dr. MACCRACKEN. EOS.

Mr. VOLKMER. Right. And we need to get on with that at this time.

Is that correct?

Dr. MACCRACKEN. Yes, sir.

Mr. VOLKMER. And we also need to plan on modelling. Does anybody disagree or agree with that?

Do we need to have funds out there for preparing for modelling or not?

Dr. LINDZEN. Yes. Modelling costs money. But, on the other hand, a specific need at the moment, and that's being addressed, is model assessment.

Moreover, I think Bob Watson was saying, I think there's an important need to recognize that modelling is a subset of theory, that there's a lot of effort that needs to be put into understanding the system and that isn't a mechanical task.

Mr. VOLKMER. Right.

Dr. LINDZEN. And it's a cheap task. You remind me of something from years ago. Someone from NASA explaining to me that theory was very powerful and very cheap, but I shouldn't be under any illusion that no one would give a penny for theory unless they also were paying for large instruments.

Mr. VOLKMER. Well, the reason I ask the question is because this Committee has decided for this coming year, under our authorization bill, to cut both of those programs.

To me that doesn't make sense. But that's what this Committee decided to do, to cut the program for the EOSDIS and to cut the program for algorithms, which is preparation for modelling.

What do you say, Dr. MacCracken?

Dr. MACCRACKEN. That's true. We're very disappointed that cuts will be occurring. We understand that actions are sometimes necessary.

Mr. VOLKMER. Well, it's still up to Appropriations.

Dr. MACCRACKEN. But it will certainly have a very difficult impact on the program to not have EOS going forward aggressively or to not have the research there.

We have this continuing balance that we have to worry about.

If I can come back just a moment to your question on data, sir.

The U.S. policy on data is to provide full and open access. It doesn't quite say free because we do try and encourage charges for the cost of reproducing. But we felt very much that the way to ensure that everyone can get at the data is to have full and open access.

There is not only the EOSDIS system of NASA, but all of the other agencies in the USGCRP have joined together in a global change data information system to make all their data available in a common way so that everyone can get access to as much as they want for whatever analyses they want.

Indeed, EOSDIS, with satellites going up, it's going to be vital to make sure that we can process that information. It would be a shame to not have the ability to get the information out.

Mr. VOLKMER. That's what I'm getting at.

Dr. MACCRACKEN. We also, of course, and I'm modeler, so I'll speak from that bias, it's vital that in parallel, we be going ahead with the analytic effort, the empirical efforts to see what you see in the record, to try and determine what you can from the record, but also to be trying to understand theoretically what's happening.

If we could avoid using models, that would be very nice. We'd like to be able to do an experiment or we'd like to be able to look at historical information.

But what is happening as a result of human activities are very rapid changes in atmospheric composition and we don't have very good evidence. There are some empirical ways to go, looking at ice, glacials, and looking at other kinds of things. None of them are particularly satisfactory. They all sort of are encouraging, but not satisfactory for making a prediction for the future.

So we must keep a balanced program between observations and theoretical efforts and modelling.

Chairman WALKER. I think it's important also to keep the record clear here.

While we did in fact call for some cuts in the program in the algorithm areas, one of them, they were largely cuts based upon what we believe the NRC study has told us, and that is that the EOSDIS program is in need of major restructuring.

It was our version of what the restructuring savings might be, not an attempt to cut out the data stream.

And secondly, most of those cuts are based upon our belief that there may be better technology than going the route of CHEM-1 and PM-1. There's obviously a disagreement about that within the community. But that's our judgment and we don't think that PM-1 and CHEM-1 are affordable in the out-years.

The Administration is going to come forward with a budget to tell us how they're going to do that. We'll be very happy to evaluate the budget as to how they are going to do this and still cut the NASA budget back to $13 billion by the year 2000.

That's something that we're going to be very interested in seeing in the couple of weeks ahead.

But I think it's necessary here to keep the record clear of what we thought the appropriate kinds of priorities are.

Mr. VOLKMER. My only comment back to the Chairman is I didn't know he was such a good mindreader, that because the cuts were made before the NRC report came out.

Undoubtedly, he knew what the NRC was going to do. That's why he made the cuts.

Chairman WALKER. No. I'm saying the cuts were confirmed by the NRC report. We, indeed, made these judgments early on and the NRC report in fact specifically said that the kinds of things that we were talking about in the EOSDIS program are in fact changes that need to be made. It's a restructuring that needs to be made.

It did in fact confirm. That's the reason why I'm enthusiastic about the NRC report, as I said earlier in this hearing.

Mr. VOLKMER. I think you'd better reread the NRC report in light of what you're doing.

Chairman WALKER. I don't have any problem—I have read it, Harold. Have you?

Mr. VOLKMER. Yes.

Chairman WALKER. Good. I'm glad someone has.

Mr. VOLKMER. It doesn't say what you say it does.

Dr. LINDZEN. What it did say——

Chairman WALKER. No. Let me just—you don't think that the report calls for restructuring of the EOSDIS?

Mr. VOLKMER. I'm not saying that, no. I'm not saying that.

Chairman WALKER. Good.

Mr. VOLKMER. But not the EOS. And it doesn't say that we need to do away with PM-1 or TRMM, or that we should even delay them. You're delaying them.

Chairman WALKER. No, no. I didn't say it said that. I said, though, that with regard to EOSDIS, that it called for major restructuring.

Mr. VOLKMER. But not cut in funds.

Chairman WALKER. Our cuts in the algorithms were based upon our calculation of that—well, yes.

Mr. VOLKMER. But not cut in funds. Restructuring doesn't mean cut in money.

Chairman WALKER. Again, if you were here for the testimony earlier, they made the point that under the law, they cannot suggest ways in which to cut the monies. That's up to policy-makers.

And I realize that some people on your side would spend us blind. We don't think that that's the appropriate way to approach these issues.

Dr. Watson, and then I think that we're past 2:30 here, so I think we're going to call it a day.

Dr. WATSON. Yes. As you say, the Academy did call for a restructuring of EOSDIS. It did also call to do PM-1, as it's currently configured.

Chairman WALKER. That's right.

Dr. WATSON. The Administration does feel very strongly about that because that also has significant ramifications for convergence of the NOAA-DOD satellite program where we see those instruments being developed for PM-1, potentially having cost savings in the out-years, as we move into a fully converged program, which we're also trying to save money by working with the Europeans.

Chairman WALKER. And that's where we have, in all honesty, a legitimate argument about what the technologies are that drive us toward cost savings.

The case can be made, and the Administration does make the case, that they will get those kinds of cost savings.

My concern is that that may not be the case, and that in fact, there may be some technologies that have a better chance of giving us cost savings, not only in the out-years, but cost savings up front as well.

And I think that's a legitimate discussion to have, without arguing whether or not the science that would be received from them is the right science.

Dr. MacCracken, did you have one final point?

Dr. MACCRACKEN. Yes. I just wanted to conclude by showing an interesting report that is evidence of industrial participation in this project.

It turns out the Electric Power Research Institute has joined with some of the utility consortia from overseas to undertake just the kind of model evaluation that Dr. Lindzen was talking about.

They put out a very interesting atlas. They ran the models in the way they wanted to. They've done the analyses in the way they've wanted to. They've done a great deal.

So we very much welcome the notion of industrial participation in these activities in a good, constructive way. They've been doing it. They ended up paying mainly only for computer time and not

for the time of any of the people. But they at least are doing it and they are starting to look at a continuation of this effort.

Chairman WALKER. Well, again, I want to thank the panelists. This has been a very useful discussion, a good overview of it for the Committee, and we thank you for your participation.

With that, the hearing stands adjourned.

[Whereupon, at 2:40 p.m., the hearing was adjourned.]

[The following material was received for the record:]

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May 2, 1996

The Honorable George E. Brown, Jr.
U. S. House of Representatives
Committee on Science
Washington DC 20515-6301

Dear Congressman Brown:

I am pleased to have the opportunity to address your follow-up questions for the record pertaining to the hearing before the Committee on Science of the U. S. House of Representatives on March 6, 1996.

The attachment provides specific detailed responses to each of the very thoughtful questions that were posed. As a general comment, I would suggest that a challenge for all of us engaged in the study of the global environment is to find a helpful means to use in providing a summary of the information that is needed by decision-makers such as yourself in order to be able to consider some very difficult decisions about the world we will leave to our children and grandchildren. To accomplish this assembly of information, the scientific community has been relying on the open and carefully peer-reviewed development of international assessments as the most widely agreed-upon means to provide a balanced information base. While those of us involved in the assessment process tend to believe it should be the primary means of providing tested information, it is, of course, natural that there will be a range of perspectives. Just as there are those who believe that the Intergovernmental Panel on Climate Change (IPCC) is overstating the case, there are a number of scientists who think that the IPCC is requiring too much certainty before drawing conclusions. I believe that hearing from only critics with one of these perspectives gave an unfortunate, and misleading, perception that the IPCC is one-sided in its findings. In fact, an extraordinary amount of effort went into the IPCC Second Assessment Report to ensure that is presented a balanced and well-documented statement of what is known and not known and with how much certainty. The full IPCC Second Assessment Report is to be published in the near future and we will provide you (and others on the Committee who may be interested) copies as soon as they become available.

As I indicated in my statement, while skepticism is an essential part of science and is welcomed in the IPCC process, it must be as rigorous in its statements as are the statements of scientific findings. What my answers seek to provide is some more of the background information and explanation that underpins the IPCC results, information that seemed to be underplayed or obfuscated by some of the critics who also provided testimony at the March 6 hearing. I hope that you will find the answers helpful.

If I can be of further help in responding to questions or in providing information, please contact me.

Sincerely yours,

Michael C. MacCracken
Director, Office of the USGCRP

c. The Honorable Robert S. Walker
Chairman, Committee on Science
U. S. House of Representatives

Questions for Dr. MacCracken

1. In your testimony, you indicated that sulfate aerosols could have effects on the temperature in regions where there are not aerosols, and even in the Southern Hemisphere. Please explain how it might occur that a response occurs where there is not a change in radiation.

Answer: Sulfate aerosols are small particles in the atmosphere that can alter the fluxes of solar radiation, thereby having an ability to influence the climate. Aerosols are formed by the reaction of atmospheric oxidizing species with sulfur dioxide emitted as a polluting component of fossil fuel combustion. Because sulfur dioxide is quite reactive and because sulfate aerosols are removed from the atmosphere relatively rapidly by contact with surface vegetation or by rain (thereby acidifying the precipitation), the sulfate aerosol concentrations are highest near and downwind of source regions (primarily coal-fired power plants).

Aerosols tend to scatter solar radiation, making the sky appear whiter and reflecting some of the incoming solar radiation back out into space (just like clouds). It is also believed that aerosols can increase the reflectivity of clouds for the short time they are present in clouds before being removed in the rain. Both of these aerosol-induced effects on solar radiation, which under most circumstances reduce the heating of the air and the land and oceans, can, of course, only occur where there are aerosols. However, once the aerosols affect the temperatures in one region of the atmosphere, they will induce a number of effects that lead to climatic changes in other regions.

Most fossil fuel combustion occurs in the Northern Hemisphere, so this is where most of the forcing due to sulfate aerosols occurs. However, there are emissions in the Southern Hemisphere. In addition, there are significant emissions of aerosols from biomass burning in the tropics and the Southern Hemisphere. Thus, it is incorrect to suggest that anthropogenic aerosols are only present in the Northern Hemisphere. Even were sulfate aerosols present only in the Northern Hemisphere, the Southern Hemisphere would be affected by the global response to forcing; however, with aerosols present in both hemispheres, there will most certainly be effects in the Southern Hemisphere.

Climatic effects from aerosols occur first simply by creating a relatively cool region. This, in turn, leads to changes in the hemispheric circulation pattern as a result of the new temperature gradients. Just as a new snowfall over the midwest or a warming in the tropical Pacific Ocean can create a warming or cooling that alters atmospheric temperatures and then changes the circulation, aerosol-induced cooling can do likewise. For long-lasting effects such as El Nino events, correlation analyses show that the long-distance effects are present throughout both hemispheres--such effects have even been given the name "teleconnections" and are the basis for such patterns as the Pacific-North America (PNA) and North Atlantic Oscillation (NAO). There is simply no doubt that altering radiation in some regions will have effects over the hemisphere, and even throughout the world.

That there would be effects in the Southern Hemisphere as a result of sulfate aerosols in the Northern Hemisphere is also indicated by events such as volcanic eruptions and changes in the Earth's orbital elements that caused global glaciations--when one hemisphere becomes cooler as a result of some perturbation to the radiation balance, the other hemisphere will give up some of its heat to help spread out the cooling. With aerosols present in both hemispheres, both hemispheres will respond.

For Dr. Michaels to suggest that aerosols should be having no effect in the Southern Hemisphere because the temperature response is not correlated with where the aerosols are is simply bad science; that there are also aerosols present in the Southern Hemisphere simply adds to his erroneous conclusion. (Dr. Michaels makes a similar

error in his attempt to dismiss the potential for changes in stratospheric ozone to be affecting the global temperature.) Any perturbation to the radiation balance will have consequences that spread out over the globe, and these responses can be detected if the original change is larger than the natural variations of the system (climatic noise).

2. Your figure [Figure 3 in your written testimony] shows that 1995 is among the warmest years on record. There has been some discussion of this in the press, and of a group in the United Kingdom presenting its conclusion on 1995 before having the data for December of 1995. Please explain what this was all about. Did the UK group jump the gun? Please also indicate what the status is of the availability of their data, as there was apparently some controversy about this.

Answer: Except for years markedly affected by volcanically induced cooling and by the cold phase of the El Nino/Southern Oscillation, the 1980s were very warm. This warmth continued into 1991 and was then interrupted by the cooling due to the injection of stratospheric sulfate aerosols caused by the very large Mt. Pinatubo volcanic eruption in the Philippines. The year 1992 was quite cool (although still about 0.6 C--about 1 F--above a comparable period of unusually cool temperatures that occurred following the very large volcanic eruptions during the first decade of this century). Recovery from the Pinatubo-induced cool temperatures started in 1993, continued in 1994, and warm temperatures were very evident in the monthly records throughout 1995. Anticipation of this was leading to many requests for the final results.

The Climatic Research Unit (CRU) of the University of East Anglia and the Hadley Centre of the UK Meteorological Office issued a statement to the press the first week of January (approximately January 4-5) of this year reporting on the temperatures for the full year of 1995. For this estimate they had the ocean data for all 12 months and the land data for the months January through November. For the December land data, they used a proven regression technique to derive an estimate for the Northern Hemisphere land area temperature anomalies based on the middle tropospheric data that they did have available; the only missing information was for December for the relatively limited areas of land in the Southern Hemisphere, for which they assumed the same deviation as for the Southern Hemisphere oceans. Their analyses suggested that 1995 annual average temperature as 0.40°C above the mean for 1961-90. In the few months since that original estimate, the estimated global anomaly using the full set of 1995 data has been recalculated as 0.39°C rather than 0.40°C above the 1961-90 mean, showing the very high accuracy of their regression technique. This makes 1995 significantly warmer than the next warmest year, which was 1990 at 0.36°C.

A second group keeping such records is the NASA Goddard Institute for Space Studies in New York. In their record, which focuses mostly on temperature changes at measurement stations and does not include ship records of ocean temperatures, 1995 was the second warmest year, just barely cooler than 1990. Some critics have tried to make a big issue of this difference, overlooking the differences in how the records are compiled (which will give slight differences) and the fact that what is critical is the overall warmth of the 1990s.

That the Microwave Sounding Unit (MSU) satellite record showed a sharp cooling in December and that the year was in the middle of the years for the last 17 years (so a much shorter record) is an interesting difference from the surface temperature thermometer record. It is important to remember, however, that the satellite instrument is *remotely sensing* the temperature of the atmospheric layer from about 5,000 to 30,000 feet over a relatively large region, but it is not directly measuring the surface temperature as the thermometer record of surface temperature does. Quite a number of studies are underway to better understand the reasons for the differences between these records. Among the factors being considered in these analyses are the different ways in which temperatures are determined, the different factors affecting the temperatures, the

effects on the MSU record of shifts in atmospheric circulation, and the different locations of where the two records show changes and variations. The USGCRP will be sponsoring a special seminar on these issues on May 20, 1996 in B-369 of the Rayburn House Office Building.

There have also been some questions about the availability of the temperature data. The CRU data are available over Internet; however, getting the data requires a specific request and the signing of an agreement form to satisfy the UK Meteorological Office that the data will not be used for commercial gain. Because it takes some effort to process both surface station and ship data, it does sometimes take a few weeks for the data to be fully assembled and made available. What apparently raised the concern early this year was that Dr. Balling asked for data in early January while one of the people handling the requests was attending a scientific meeting. Had he asked a few weeks later, he could have gotten the data that are shown in Figure 3 of my testimony.

It is interesting to note that, to the knowledge of the CRU group, there has apparently been no follow-up request for the data even though there continue to be erroneous claims that the data are not available.

3. Dr. Davis commented that his submissions to the IPCC were not included in the IPCC report. Could you, perhaps by consulting with the lead author of his chapter, determine why Dr. Davis' input was supposedly not considered?

Answer: As suggested in the question, I have contacted Dr. Neville Nicholls of the Bureau of Meteorology Research Centre in Australia, who was the lead author of Chapter 3 of the IPCC Working Group I assessment, the chapter for which Dr. Davis submitted materials. For the benefit of the Committee, I include a copy of Dr. Nicholls' letter to me, which provides a full explanation of the matter.

I would summarize his comments as follows:

a. As a result of a relatively late submission of input through an IPCC co-author located in Moscow, the materials of Dr. Davis arrived late in Australia, which resulted in him not getting a letter indicating that because of the extensive submissions and the limits on the length of the chapter, not all material could be included.

b. Materials submitted by various authors on trends in atmospheric circulation were nonetheless included in the first draft of the chapter sent out to reviewers. The results, however, were criticized as conflicting and generally unreliable for deriving indications of trends. For this reason, it was believed that indications of change in this variable should not be included, even though many demonstrated trends in contradiction to the results of Dr. Davis.

c. Dr. Davis results on changes in extreme were included in the IPCC Chapter 3 and Dr. Davis did not comment on this write-up in the review process.

d. Dr. Davis (and also Dr. Michaels in his remarks to the Committee) suggested that Chapter 3 should have indicated that the observed changes in temperature during this century (particularly prior to 1940) were not related to increasing concentrations of carbon dioxide. This would have been particularly inappropriate because the IPCC wanted the chapter to state only what changes were occurring and not to draw conclusions--conclusions as to the cause of changes were specifically assigned to Chapter 8 so that the sequence of chapters could first indicate what the model predictions were for temperature changes since the mid-nineteenth century.

e. Dr. Davis makes both general and specific charges about the review process. Dr. Nicholls in his letter makes clear that the charges are not well-founded; reviews were solicited and received from many scientists and nations, and the authors considered all of the comments--there was no predetermined bias about

the outcome. Similarly on the specific comments; Dr. Nicholls provides examples of how carefully the conclusions are stated.

Both Dr. Nicholls and Dr. Christy have been in touch with Dr. Davis subsequent to the hearing expressing surprise and concern about his comments and fully explaining how his results were considered along with those of others. The results of Dr. Davis did not receive any greater or less consideration than those of others, as should be the case in such a review.

I might add that the results of Dr. Davis apparently compared observations to model results for greenhouse gasses only. Given the strong presence of aerosols in the Northern Hemisphere, this is simply not appropriate and Dr. Davis should be re-doing his calculations rather than widely presenting out-of-date results.

4. Dr. Davis commented that his check of the references indicated that some of the reports were not available for review. Please provide for the record a copy of the IPCC policy for consideration of documents and results in their report. Do you know of any cases where the reports were not made available if requested?

Answer: A copy of the IPCC guidelines is attached. The relevant text is as follows (quoted from the section on Reports Accepted by Working Groups, point 2 on Organisation of Work): "Contributions should be in the form of text specifically written for the draft report and supported as far as possible with references from the peer-reviewed and internationally-available literature, and with preprints of any unpublished material cited; clear indications of how to access the latter should be included in the contributions. Lead authors will work on the basis of these IPCC contributions, the peer-reviewed and internationally-available literature including scientific and technical publications prepared by national governments and scientific bodies, the latest reports from researchers that can be made available in pre-print form for IPCC review, and IPCC supporting material." Thus, Dr. Davis' characterization of IPCC procedures is generally incorrect--the key requirements are that the material be suitably prepared and available, with the IPCC process *itself* serving as the review process for the newest materials. The IPCC also requires that the reports be available, and I know of no case where a paper that was requested was refused.

Several additional points should be made. Because the assessment which the IPCC prepares draws from the international scientific community, it is important to recognize that different nations have different methods and traditions of review; as a result, published journal articles are not the only accepted mode of submitting information for consideration. Other acceptable forms include reports from major laboratories that have received internal review, data sets of various types, books (which sometimes are not reviewed), etc. Second, IPCC faces the challenge of being asked to be up-to-date as well as to be authoritative; to accomplish this, the IPCC generally accepts materials that are in the publication process at the time of the completion of the final review-draft of the chapters (for Working Group I, this was September of 1995).

The check of the references that Dr. Davis made was for the first review draft in April, 1995 and focused on only one part of the materials that are acceptable to the IPCC. In any case, by the time of the September 1995 IPCC draft, there were only a few papers listed as "in press" and by the time of publication in June 1996, most of the reports listed as "in press" should be published. Had the IPCC insisted that no papers not already published by about January 1995 could be considered, the IPCC review would have been seriously out-of-date when it was published. It should also be noted that the IPCC review process typically involves more than a hundred reviewers per chapter, so is much more thorough than any review by a journal. As such, Dr. Davis' comments are based on a misunderstanding of the IPCC process, which clearly provides the most authoritative assessment of the state-of-the science.

5. Dr. Michaels indicated that in 1992 a test was not done comparing the transient model simulations against the observed climate. Can you please explain why this comparison was not done?

Answer: The reason that the comparison Dr. Michaels suggests was not done in 1992 is that no realistic transient model simulation (i.e., using a general circulation model and simulating the historical period) had been made. The first, early attempts to represent the historical period in a model simulation were not completed until 1995, and the comparison suggested by Dr. Michaels is included in the new IPCC report even though the model simulation is not a fully realistic simulation, as explained below.

The only transient (time-dependent) model simulations that the 1992 IPCC report presents are for the hypothetical case of starting from the near-present carbon dioxide concentration and increasing the concentration by 1% per year at a compound rate. This is not at all similar to what has happened since the industrial era began in the 19th century when the carbon dioxide concentration was 25% lower than at present. In addition, the rate of rise in the model simulations described in the IPCC 1992 report was much more rapid than is actually the case, and time scaling, as done by Dr. Michaels to try to make an adjustment for this, has many shortcomings. Finally, as clearly stated in the 1992 IPCC report, the results presented in that report were *not* a prediction of temperature change, but rather what might happen (given the unrepresentative 1% scenario and the different starting point) as a result of *only* the change in carbon dioxide concentration. As the 1992 IPCC report made clear, a prediction (or realistic simulation) requires that all of the important factors, both human-induced and natural, be considered, and this was not then possible; for example, aerosols were a prominent factor that was not being considered. This caveat also applies, but less significantly, to the 1995 IPCC comparison; in the 1995 case a model simulation was actually started in the mid-nineteenth century, the lower preindustrial concentration was used as the starting point, and the increase over time was at about the right rate; however, caution must also be applied regarding the 1995 comparison because changes in ozone, the effects of aerosols on clouds, the effects of solar and volcanic forcing, and other forcings were not included. A fully realistic simulation remains to be done.

Thus, the comparison that Dr. Michaels asked about regarding the 1992 IPCC assessment was not possible then (or even fully now) and it would not have been appropriate to do at that time.

6. Dr. Michaels asked about the publication status of your final figure that was attempting to indicate how solar forcing may be affecting the climate. Dr. Lindzen also criticized your final figure as the way that science should not be done, suggesting that we do not have an aerosol record, that the absence of volcanoes could not have contributed to the warming before 1940, etc. Dr. Balling suggests that the MSU record shows disagreement with the figure. Would you please respond to their criticisms.

Answer: I regret the confusion that was generated because I did not have available the citation for the figure at the hearing. The figure that I showed is included in Chapter 8 of the 1995 IPCC Working Group I report, which I should have noted on the figure. The first two panels of the figure were included in the first draft of the IPCC report, which had been distributed to Dr. Michaels last May; the third panel of the figure was, however, not included in the first draft of the report, being added as the result of comments on the first draft of the report. (The revised figure received no comments in the final IPCC review process). The figure was also presented at a National Academy of Sciences meeting (which Dr. Lindzen attended, and at which he did not comment on the figure.) The figure is presently in an article entitled "The observed global warming

record: what does it tell us?" by Dr. Tom Wigley that is currently under review for publication in *The Proceedings of the National Academy of Sciences* .

I must respectfully disagree with Dr. Lindzen's comments. The model used by Dr. Wigley, although simplified compared to the general circulation models (GCMs) based on fundamental principles of physics, has been well-checked against the GCMs in quite a number of cases. The first panel of the figure is based on well-established records of greenhouse gas concentrations, and the second panel is based on a sulfate aerosol record that is derived based on some careful reconstructions of coal combustion, emission rates, and chemical model simulations of aerosol production (the models are tested against the present climate and aerosol distribution). In the third panel, Dr. Wigley used an estimate of the changes in solar radiation estimated independently of his work (and published in a peer-reviewed journal) and looked at the response of his model, investigating whether changes in solar forcing could have contributed in an important way to past climate change (a suggestion put forth by many critics). The diagram is given in the IPCC report only to show that, in contradiction to views of some critics, solar warming could not have been a major factor in the overall warming and that there is no serious inconsistency between model estimates of past global warming and observations.

With regard to the climate record early this century, I was simply pointing out in my oral testimony that there were major volcanic eruptions in 1902-3 and 1911 (as well as earlier in the 1880s), among other periods, and these eruptions would have been expected to have cooled the climate (just as Mt. Pinatubo did). It would then follow that the period after the eruptions would see some recovery from this cooling. An examination of the record shows this to have likely been the case, so at least some of the warming leading up to the secondary peak in 1940 was due to the recovery from volcanically induced cooling (and some to solar, and some to greenhouse gases). It is important to note that the estimate of the IPCC that there has been warming of 0.3 to 0.6°C since the mid-19th century is starting from a baseline during that period that is somewhat above the cool period in the first decades of this century--thus, subtracting the full amount of the warming from 1910 to 1940 from the 0.3 to 0.6°C, as Dr. Michaels proposes, is simply not correct. Note that if the recent warming is measured from the low temperatures of the first decade of this century up to the 1990s, then the warming has been roughly 0.7°C (and, hence, greater than the IPCC estimate). Alternatively, if the warming is measured from 1910 to the minimum following the Mt. Pinatubo eruption, thus approximating comparable natural perturbations, the warming is about 0.5°C, just as the IPCC suggests. While the various contributions of volcanoes to the temperature anomaly record is not proven, this is a quite plausible hypothesis, and is the working hypothesis that I would offer in response to Dr. Lindzen's challenge to state my hypothesis.

Dr. Balling suggests that the figure that I showed does not agree with the MSU (Microwave Sounding Unit) record. First, my figure shows a record of the surface air temperature, whereas the MSU record is of the 5,000 to 30,000 foot layer of the atmosphere--Dr. Balling is thus suggesting a comparison of two different quantities. The differences between the surface air temperature record and the temperature of the 5,000 to 30,000 foot layer above the surface are being analyzed in studies by Dr. Kevin Trenberth of the National Center for Atmospheric Research, Dr. Phil Jones of the University of East Anglia, and others. Thus, great care must be taken in the comparison so glibly presented by Dr. Balling.

Second, a point made repeatedly by the critics is that the MSU record does compare well with the radiosonde (weather balloon) record. However, they generally fail to note that over the more than 30 years of the radiosonde record (as compared to the 17-year record of the MSU), the trends derived from the radiosonde and surface temperature records compare reasonably well. Over the period of the MSU observations, one would expect some differences due to the effects of ozone depletion in the stratosphere on the

temperature of the upper troposphere (and, hence, on the MSU record) and due to the different ways in which a temperature change estimate is generated from the two records. Assessing the effects of stratospheric ozone depletion on the MSU data is a complex issue, not least because the pattern of response to ozone depletion differs from the depletion pattern.

Finally, as indicated earlier, Dr. Wigley's figure does not yet include consideration of all of the factors (e.g., volcanic eruptions, El Nino/Southern Oscillation variations) that affect, particularly, the intra- and inter-decadal fluctuations that dominate the MSU record. Further, unlike Dr. Christy, who is a co-author of the MSU record, Dr. Balling does not account for these factors in his analyses of the MSU record. For these reasons, Dr. Balling's criticism is neither valid nor pertinent.

7. Dr. Michaels asks why a statement is not included in the IPCC report about the fact that a significant part of the warming occurred before 1930 and thus could not be due to the greenhouse gases. Could you please comment about what is said about the timing of the warming in the IPCC report? Were not forest and grassland burning and land clearing contributors to the early rise in CO_2 concentration along with fossil fuel use?

Answer: First, as explained in the response to question 3 above, Dr. Michaels (along with Dr. Davis) had suggested that such a statement be included in Chapter 3 of the IPCC report, which reviewed evidence of climate change. This would have been totally inappropriate because, as explained in Dr. Nicholls' letter, this chapter was simply to describe what was happening; discussion of the adequacy or inadequacy of particular explanations for the changes were to be left for Chapter 8 of the report. It should also be noted that Chapter 3 does not include statements either suggesting that the warming is due to greenhouse gases or that it is not--the only statements included are that changes had occurred.

Before commenting on what is included in Chapter 8, it is important to note that the premise of the question is also incorrect. There was significant positive forcing prior to 1930. (Actually, in his testimony, Dr. Michaels used the year 1950 for his charge--certainly there was significant positive forcing prior to 1950). This forcing came as a result of carbon dioxide and methane emissions from fossil fuel combustion, natural gas venting, changes in land use, the increase in cattle and other farm animals, and other factors. In addition, the negative forcing from sulfate emissions was somewhat limited because coal-fired electric power plants generally did not have tall stacks (which lengthens the lifetime of sulfate aerosols in the atmosphere) and may have been further limited by high levels of dark sooty particles that actually tend to warm the atmosphere. Because the greenhouse gas concentrations also changed relatively slowly as compared to the somewhat sharper increases in recent decades, the climate system also had more time to adjust to the early concentration changes than to the more recent changes.

Dr. Michaels also misstates the amount of warming during the 1910 to 1940 period that might be counted as due to the greenhouse effect. As explained in answer to question 6, the IPCC estimate of 0.3 to 0.6°C warming goes back to the mid-19th century. Late in the 19th and early in the 20th century, there was a cooling that was perhaps 0.1 to 0.2°C, due at least partly to volcanically induced cooling; thus, of the rise of 0.3°C from 1910 to 1940 that Dr. Michaels refers to, about half may have been due to recovery from the volcanically induced cooling. The residual warming of about 0.15°C from greenhouse gases prior to 1940 is certainly plausible. Furthermore, internal variability almost certainly played a part. Thus, the main reason why the point that Dr. Michaels wanted to see included in the IPCC Second Assessment Report was not included was that it is incorrect. The Figure referred to in Question 6, which appears as Figure 8.4 in the IPCC Working Group 1 report and is referred to in my testimony, and which does not include the effects of natural variability in its model

projections, clearly shows that there is no inconsistency between model results and any part of the observed record.

Finally, with respect to what is said in Chapter 8, the chapter uses the changes over the period before 1940 in its geographic analyses (to the extent that observations are available) and so the analyses fully consider this period. It is true that not all of the variations have been fully explained, and in fact such would be an unreasonable expectation because of the variability of climate and our limited information for this period. Progress, however is being made. By his question, Dr. Michaels mischaracterizes what is known and understood about this period.

8. Dr. Lindzen asked about error bars on the tree-ring data. Could you please indicate your understanding about the accuracy of the tree-ring record? Is it generally consistent with other measures of temperature change over this period?

Answer: First, I should clarify that the record shown is drawn from a combination of 16 proxy record sets that include tree-rings, ice cores, and documentary records from North America, Europe, and East Asia. Dr. Lindzen is correct that the absolute accuracy of the tree-ring data (and the ice core and even documentary data) is not sufficient to indicate precisely what the actual temperature conditions are at a particular time. However, what is shown in this record are the relative changes in a number of records that span this period--that is, what is shown are the changes from many long-lived single trees (or overlapping tree-ring records from the same types of trees in the same region), from ice cores, and from documentary records that provide consistent measures of change over time. Such time series data show variations in the decadal average that can, in the case being described, be expressed in terms of variations in the summer temperature. What the Figure in question shows is that the 20th century is particularly warm compared to all centuries back to 1400 AD, when the proxy records began. Temperatures measured in boreholes drilled into the ground also yield the same result (and they actually show a somewhat larger warming over the same period because they sample the temperature change for the whole year). Some mountain glaciers also show evidence that the recent warm period is warmer than any period back perhaps even to onset of the last glacial period (which would mean back to about 80,000 years ago or earlier).

There is thus significant indirect evidence that this century is the warmest in a very long time, and the thermometer record for the last 130 years shows that the 1980s and 1990s are the warmest this century. While it would be nice to have better records, that there are no contradictory records is also an indication that we can have reasonable confidence in the IPCC finding that the balance of evidence suggests that there has been a discernible human influence on the global climate.

Attachments:

1. For Question 3: Letter dated April 19, 1996 from Dr. Neville Nicholls of the Bureau of Meteorology Research Centre in Melbourne, Australia.

2. For Question 4: Intergovernmental Panel on Climate Change (IPCC) Procedures for Preparation, Review, Acceptance, Approval and Publication of its Reports, approved at the Ninth Session (Geneva, 29-30 June 1993).

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April 19, 1996

Dear Mike,

I have received a copy of the Testimony given by Dr Robert E Davis to the U.S. House of Representatives Committee on Science, March 6, 1996. Some parts of his testimony touch on the content of Chapter 3 of the IPCC Second Scientific Assessment of Climate Change, and on the way this Chapter was prepared. Since I was the Convening Lead Author of that Chapter I thought I should respond to some of the points raised by Dr Davis in his testimony. I have already communicated with Dr Davis regarding the parts of his testimony related to my Chapter.

Let me first address how the "circulation" issue, and Dr Davis's contribution specifically, was dealt with. I had hoped at the start of the process of drafting this Chapter (in late 1993) to include more information regarding how the atmospheric circulation had varied, relative to the little that was included in previous IPCC reports on this subject. We therefore invited many contributions on this topic, and drafted an extensive section. This was sent to several reviewers in mid-1994 and was harshly criticised. The essence of the criticism was that many of the studies were apparently conflicting and many used meteorological analyses which were considered unreliable for detecting long-term variations. Based on this advice, and the need to substantially reduce the length of the Chapter, we decided to concentrate on just a few large-scale indices, essentially those which had been examined in earlier IPCC assessments. I was disappointed that we could not do more on the circulation issue but I accepted that more work needs to be done in this area, to forge a consensus on changes and variability in many aspects of the atmospheric circulation. So, Dr Davis's contribution was excluded from the final draft along with most of the contributions we had solicited on possible changes in circulation. Could I add that many of the other contributions on this topic purported to demonstrate trends in circulation through the 20th century which might be attributed to anthropogenic causes. The overall balance of this section, if we had included all the contributions, would have suggested an anthropogenic influence. But I stress that we thought the data were not sufficiently credible to allow such a suggestion, so we did not include these contributions.

Dr Davis, in his testimony expresses some annoyance that the only part of his research we cited was his demonstration of the increasing frequency of intense nor'easters. I do not understand his objection to this statement - it is a factual statement of Dr Davis's result, and placed in a section on weather extremes. I had assumed he was happy with this text, because he had already seen it in the draft (and not commented upon it). So, the comment in his

testimony on this point was a surprise. I do not understand how what we say in the Chapter can be taken to "provide evidence of more extremes caused by global warming" because we nowhere reach such a conclusion. Our conclusions regarding extremes I have included below - we say nothing of this sort.

Dr Davis notes, in his testimony, the final sentence of his Contribution, implying that because we did not include this sentence the Chapter is biased. His final sentence was "Thus, there is little consistent observational evidence in the Northern Hemisphere's climate history to indicate that the circulation has been significantly altered by increasing concentrations of CO_2 and trace gases". At the start of the drafting process for this Chapter (in late 1993) I determined that such statements, discussing possible attribution of any changes, would NOT be included in Chapter 3, which was to be simply a description of observed changes. Chapter 8 was to assess attribution of any changes to possible causes, and does so. If we had included Dr Davis's statement, we would (to avoid charges of bias) have had to assess every single possible change documented in the Chapter, to note whether it could or could not have reflected an enhanced greenhouse effect. This would have made the Chapter too long, incomprehensible, and duplicated the activity of the Chapter 8 lead authors. I suspect that if we had decided to include such statements, the occasional statement such as Dr Davis's would have been buried by the numerous statements to the effect that the various changes are consistent with an enhanced greenhouse effect. So, excluding such statements made the Chapter less "pro-greenhouse" than would have been the case if we had included them.

I recognise that it can be annoying to prepare a contribution to some report like the IPCC, and then not to have any part of your contribution included in the report. I know how annoying this can be because it happened to me, as a contributor, in the 1990 assessment! So I can understand Dr Davis's annoyance. This is why, in June 1994, I wrote to everyone from whom I had received a Contribution. I had not seen Dr Davis's contribution at that stage, because it was sent in May to George Gruza and the mail between Moscow and Melbourne is very slow. The letter to Contributors alerted them to the likelihood that very few, if any, of their words would make it to the final version because of our word limit and the extensive review process which was underway. I indicated in the letter that I wanted to alert Contributors to this, so that they would not be too annoyed when they saw what we (the Lead Authors) had done to their Contribution. The Contributions were meant to provide background information for the Lead Authors. With over 100 contributions, each of two or more pages, little of the original text of any contributor could have been expected to make it into the final 25 pages of text. Very few of any of the Contributors will be able to recognise any of their words in the final version of the Chapter.

Could I now turn to Dr Davis's general comments regarding the process, for instance the comment that "The editorial process was carefully controlled to give the appearance of widespread agreement". With regard to Chapter 3 I can assert and demonstrate that the editorial process was designed to facilitate criticism from scientists with a wide range of views. This was one reason I solicited contributions from over 100 scientists, many of whom had had little involvement with debates on climate change. I knew that including so many varied contributors, as well as providing the Lead Authors with valuable background reviews of many aspects of the climate change question, would ensure that the Chapter was reviewed by a wide audience, before being finalised (I knew that the Chapter would be sent to all contributors for review). I also deliberately solicited contributions from "greenhouse agnostics or critics"

including Dr Pat Michaels and Dr Robert Balling. I particularly wished to do this because I thought that, even with the best will in the world, statements which could be interpreted as biased could creep into the Chapter. Ensuring, as I had, that scientists with a wide range of views on climate change would review the draft, meant that I could hope for something approaching consensus, at the end of the process.

We received about 150 sets of comments on the draft which Dr Davis reviewed, with nearly 1000 separate comments. Each comment was considered at the Asheville meeting in June. Dr John Christy (not known as a "greenhouse proponent") was at that meeting and I asked him (as someone separate from the Lead Authors) to annotate his copy of the draft with every comment, and to consider how we should respond. I also did this and the results were discussed in a meeting with the Lead Authors and others. I can assure you, as can John, that every comment was considered carefully and where possible the text was revised in an attempt to address the concerns raised. This included all the comments raised by Dr Davis. I was interested in preparing a Chapter which could gain "widespread agreement, not in pushing a particular viewpoint". I did this by including a wide range of viewpoints amongst the Contributors and Reviewers, and by seriously considering every single reviewer comment. I do not see how I could have done more to ensure a fair and scientifically defensible Chapter.

Could I turn now to some of specific review comments made by Dr Davis, and how we dealt with them? Dr Davis stated in his testimony that the final version of the Chapter "included none of these concerns". Let me indicate a few instances where the final text has been changed as a consequence of the concerns he raised, and how his concerns were addressed.

Firstly, he was critical of the description of the recent ENSO behaviour as "highly unusual". I should note that I spent a great deal of time last year debating this point with many in the ENSO research community. There were those who thought the statement was too weak, and I had some very forthright discussions with them. There were others who seemed to think we could avoid the topic altogether. This seemed a dereliction of duty to me. So we compromised with the final wording describing the recent behaviour as "unusual in the context of the last 120 years (the period of the instrumental record)". I would be happy to defend this statement in any court of law. Weakening it further, or omitting it, would reflect bias.

Dr Davis was concerned that we seemed to be implying that the MSU data cannot be trusted. We certainly did not intend this (how could we, with John Christy, one of the major workers on the MSU data, involved?). Because of Dr Davis's comment, and our concern that he appeared to interpret our wording as biassed, we re-examined our wording in an attempt to ensure no-one could read such an implication into the Chapter.

Dr Davis was also concerned that we seemed to add a conditional clause every time "there is some data or study indicating that climatic conditions might not be unusual". We were surprised at this concern, since we had tried to avoid such implications. As a result of Dr Davis's comment we again went through the Chapter in an attempt to remove such unwarranted implications being read into it. We did, however, need to say where the data were unreliable or not sufficient studies had been done to reach an answer. We did, though, in response to Dr Davis's comment, make a genuine attempt to revise the wording to avoid implying that if there were such studies or the data were better then a "greenhouse" change would have been found.

Dr Davis expressed concern that many unpublished papers were cited in the draft. The final version contains only a few "in press" papers, and by the time the report is actually published I hope nearly all of these will have been published.

I hope I have demonstrated that Dr Davis's concerns were genuinely considered, and that the text of the chapter changed as a result of these concerns. I did my utmost to provide a balanced and unbiased summary of what the scientific community knew about observed climate change and variability. To those who suggest that the Chapter is biassed, could I suggest they consider a couple of the conclusions we reached and which are in the final version:
1. "Intense tropical cyclone activity in the Atlantic has decreased over the past few decades". Does this seem to be a biased "pro-greenhouse" statement? We went out of our way to include this statement, to try to kill the idea that hurricanes are getting more numerous and intense. Would we have done this if we intended to produce a "pro-greenhouse" chapter?
2. "The data on climate extremes and variability are INADEQUATE TO SAY ANYTHING ABOUT GLOBAL CHANGES, but in some regions, where data are available, there have been DECREASES or INCREASES in extreme weather events and variability" (I have added the emphasis here). How could we be fairer than this? Is it untrue? I certainly do not understand how this conclusion fits with the statement in Dr Davis's testimony that "The document leaves one to believe these nor'easter trends provide FURTHER evidence of MORE extremes caused by global warming" (again I have added the emphasis, to demonstrate the difference between what Dr Davis implies and what is actually concluded in the Chapter).

I was surprised to hear that my Chapter, and the method of its preparation was being criticised, with the implication that it was biased in some way towards the "greenhouse" side. You probably remember that at the Madrid meeting I publicly and successfully defended the text of the Chapter from attempts to change the wording in ways I thought were intended, by those proposing the changes, to strengthen the message that the climate was changing. For instance, several delegates to that meeting wanted me to delete the conclusion that intense Atlantic hurricane activity had been declining. I must say I have been anticipating receiving criticism for making the final Chapter too bland and concensual. I would dispute such criticisms also, but I especially dispute any suggestion that the Chapter is biased or that the process of preparation of the Chapter was designed to produce a "pro-greenhouse" result. Please ask anyone suggesting this to identify specific, incorrect statements in the text, if they can.

Yours sincerely,

Neville Nicholls
Convening Lead Author, Chapter 3, IPCC95.

IPCC PROCEDURES FOR PREPARATION, REVIEW, ACCEPTANCE, APPROVAL AND PUBLICATION OF ITS REPORTS

Approved at the Ninth Session (Geneva, 29-30 June 1993)

Introduction

The role of the IPCC is to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the risk of human-induced climate change, its potential impacts and options for adaptation and mitigation. IPCC assessments should be neutral with respect to policy, although they may need to deal objectively with scientific, technical and socio-economic factors relevant to the application of particular policies.

Review is an essential part of the IPCC assessment process. Since the IPCC is an intergovernmental body, review of IPCC documents should involve both peer review by experts and review by governments.

This paper contains the procedures for the preparation of IPCC reports which are to be published and sets out the requirements for planning within the work programmes necessary to ensure that IPCC review is carried out on a wide and representative basis and that proper provision is made for acceptance and approval processes.

IPCC Published Reports

Four categories of IPCC-published reports can be identified, each with particular requirements for review, acceptance or approval [1]:

- Supporting material
- Reports accepted by Working Groups
- Reports approved by Working Groups and accepted by the Panel
- Reports approved by the Panel.

Supporting Material

Supporting material consists of (i) published reports and proceedings from workshops, seminars and meetings within the scope of the IPCC work programme that have IPCC recognition, and (ii) material commissioned by Working Groups and Subgroups in support of the assessment process which IPCC decides should have wide dissemination. Procedures for the recognition of workshops, seminars and meetings are given in annex 1.

Arrangements for publication of supporting material should be agreed as part of the process of IPCC recognition or in commissions from Working Groups or Subgroups to prepare specific supporting material. All supporting material should be formally and prominently described on the front and other introductory covers as:

> "Supporting material prepared for consideration by the Intergovernmental Panel on Climate Change. This supporting material has not been subjected to formal IPCC review processes."

Reports Accepted by Working Groups

Reports presented for acceptance by the Working Groups at Plenary level consist principally of the full scientific and technical assessments of Working Groups I, II and III. Methodologies, such as the Methodology on Emissions Inventories and the Preliminary Guidelines for Impacts Assessments, also fall into this group, as do interim reports on particular topics requested by the Panel (e.g., reports prepared in response to the requirements of the Framework Convention on Climate Change). The subject matter of these reports shall conform to the terms of reference of the Working Group and to the work plan approved by the Panel.

Reports in this category will undergo a full expert and government review. The objective of this review is to ensure that the reports present a comprehensive, objective, and balanced view of the areas they cover. While the large volume and technical detail of this material places practical limitations upon the extent to which changes to these reports will normally be made by Working Groups or Subgroups at Plenary level, "acceptance" signifies the view of the Working Group that this objective has been achieved.

Reports accepted by Working Groups should be formally and prominently described on the front and other introductory covers as:

> "A report accepted by Working Group X of the IPCC but not approved in detail."

It is essential that Working Group and Subgroup work programmes allow proper time in their schedules for a full review by experts and governments to be carried out. The Working Group and Subgroup Co-Chairs are responsible for implementing the work programme and ensuring that proper review of the material occurs in a timely manner.

To ensure proper review, the following steps should be undertaken:

1. Compilation of lists of lead authors contributors, expert reviewers and government contacts

   At the request of Working Group or Subgroup Co-Chairs, all countries and participating organizations should identify their appropriate experts for each Working Group and Subgroup area who can act as potential lead authors, contributors or reviewers. To facilitate later review by countries, governments should also designate their respective IPCC Contacts. These should be assembled into lists available to all IPCC members and maintained by the Working Group or Subgroup Co-Chairs. The tasks and responsibilities of lead authors, contributors, expert reviewers and government contacts are outlined in annex 2.

2. Organisation of Work

   Preparation of the first draft of a report should be undertaken by lead authors identified by the relevant Working Group bureau from those experts cited in the lists provided by all countries and participating organizations, with due consideration being given to those known through their publication or work. In sofar as practicable, the composition of the group of lead authors for a section of a report shall reflect fair balance among different points of view that can reasonably be anticipated by the Working Group bureau, and should include at least one expert from a developing country.

At the earliest opportunity, Working Groups and Subgroups should inform all IPCC participating countries and organizations about who the lead authors are and the areas they are covering. Experts who wish to contribute material for consideration in the first draft should submit it directly to the lead authors. Contributions should be in the form of text specifically written for the draft report and supported as far as possible with references from the peer-reviewed and internationally-available literature, and with pre-prints of any unpublished material cited; clear indications of how to access the latter should be included in the contributions.

Lead authors will work on the basis of these IPCC contributions, the peer-reviewed and internationally-available literature including scientific and technical publications prepared by national governments and scientific bodies, the latest reports from researchers that can be made available in pre-print form for IPCC review, and IPCC supporting material.

In preparing the first draft, and at subsequent stages of review, lead authors should clearly identify disparities of view for which there is significant scientific or technical support, together with the relevant arguments.

3. Review by Experts

First draft reports should be circulated by Working Group or Subgroup Co-Chairs for review by experts. The review circulation should include:

- specialists who have significant publications in particular areas;
- lead authors, contributors and reviewers on the IPCC lists maintained by the Working Group and Subgroup co-chairs;
- IPCC participating countries and organizations;
- specialist reviewers nominated by appropriate international scientific and technical organisations (e.g., WMO, UNEP, ICSU, Third World Academy of Sciences, FAO, IOC, World Bank, Regional Development Banks, OECD).

The Working Group and Subgroup co-chairs should make available to reviewers specific material on request referenced in the document being reviewed which is not available in the international published literature.

Comments by reviewers should be made available to the appropriate lead authors.

Lead authors, in conjunction with Working Group and Subgroup co-chairs, are encouraged to supplement the draft revision process by organizing a wider meeting with principal contributors and reviewers, if time and funding permit, in order to pay special attention to particular points of assessment or areas of major differences.

The time schedule allowed for return of review comments will be constrained by the IPCC work schedule, but normally should not be less than six weeks, except when special circumstances permit only one month. More time may be required for some material. If time allows, a revised draft incorporating comments, together with any appropriate summary, should be circulated again for review by experts.

Contributors and reviewers should make full use of the draft and revised report review procedures to pursue the incorporation of their contributions in the report at the earliest opportunity.

4. Review by Governments

A revised draft should be distributed by Working Group co-chairs to governments through the designated IPCC government contacts, and to all the original contributors and reviewers.

Governments should send one integrated set of comments for each Working Group report to the appropriate Working Group co-chairs through their IPCC government contacts. They may wish to organize their own mechanisms for consulting experts in preparing their responses. Working Group and Subgroup co-chairs should arrange for a full record to be kept of all comments received and, upon specific request, should make them available.

To facilitate government review, non-government reviewers should send their further comments to Working Group co-chairs with a copy to their appropriate government IPCC contact.

The time available for return of government reviews should not be less than six weeks.

Preparation of a final draft report for submission to Working Group Plenary should be undertaken by lead authors, and Working Group and Subgroup co-chairs as appropriate. If necessary, and timing and funding permit, a wider meeting with principal contributors and reviewers is encouraged in order to pay special attention to particular points of assessment or areas of major differences. It is important that reports describe different (possibly controversial) scientific or technical views on a subject, particularly if they are relevant to the political debate. The final draft should credit all lead authors, contributors, expert reviewers and country reviewers by name and affiliation.

5. Acceptance of the Report

A final draft taking into account country comments should be distributed to all IPCC participating countries and organizations not less than three weeks prior to a Working Group Plenary meeting called to accept the report and transmit it to the IPCC Plenary. It is for the Working Group co-chairs to assess the time necessary for completing action in a timely manner, according to the complexity of the task and to the amount of work already in hand within the IPCC or other bodies already working in the field.

Reports Approved by the Working Groups and Accepted by the Panel

Reports approved by the Working Groups and accepted by the Panel will principally be the three Executive Summaries and the three Summaries for Policymakers, prepared by the respective Working Groups, of their full scientific and technical assessments. The Summaries should be subject to review by both experts and governments and to final line-by-line approval at a Plenary meeting of the appropriate Working Group. Responsibility for preparing first drafts and revised drafts of the Executive Summaries and the Summaries for Policymakers lies with the respective Working Group and Subgroup co-chairs as appropriate. The Summaries may be prepared concurrently with the preparation of the main Working Group reports or following the acceptance of these reports by the Working Groups. Not less than six weeks should be

allowed for the review of the draft summaries, and the final draft for line-by-line approval should be submitted to the Working Group not less than one month before the Working Group meeting to approve the Summaries.

Approval of the Executive Summary and the Summary for Policymakers by the Working Group Plenary signifies that they are consistent with the factual material contained in the full scientific and technical assessment accepted by the Working Group. These Summaries should be formally and prominently described as:

> "A Report of Working Group X of the Intergovernmental Panel on Climate Change."

Working Group approval of the Summary for Policymakers constitutes approval by the full Panel because the approval process is open to all countries. However, it is necessary to review the reports in general, note any substantial disagreements, and formally adopt them in order to prepare a synthesis IPCC report.

All Summaries should be transmitted to the full Panel at least one month ahead of the IPCC session at which the IPCC report is to be approved. More time may be necessary depending on the nature of the report.

Reports Approved by the Panel

The Panel will base its synthesis report on a review of the Working Groups' Summaries, will record any substantial disagreements not already taken into account and will include the Summaries in its report.

The IPCC synthesis report is intended to provide an overview and synthesis of the Executive Summaries and the Summaries for Policymakers of the Working Groups. It should receive full review by participating governments and organizations.

Initial drafting of the IPCC synthesis report will be undertaken by the IPCC Chair and Working Group Co-Chairs. The draft should be made available for government and participating organization review for not less than six weeks. The revised draft should be made available to participating governments and organizations not less than one month before the Panel Plenary meeting called for the purposes of line-by-line approval of the draft.

The report consisting of the IPCC synthesis report and the Summaries of the Working Groups is an IPCC report and should be formally and prominently described as:

> "A Report of the Intergovernmental Panel on Climate Change."

ANNEX 1

IPCC WORKSHOP POLICY

IPCC workshops, seminars and meetings are those that have been agreed in advance by an IPCC Working Group or by the Panel as useful or necessary to completion of the Working Group's work plan or a task of the IPCC. Only such activities may be designated as "IPCC" workshops, seminars or meetings. Their funding should be assured in advance from sources other than the IPCC regular budget and should include provision for participation of experts from developing countries and countries with economies in transition.

The proceedings of IPCC workshops, seminars and meetings should normally be published. Such proceedings should:

- include a full list of participants
- indicate when and by whom they were prepared
- indicate whether and by whom they were reviewed prior to publication
- acknowledge all sources of funding and other support
- indicate prominently at the beginning of the document that the activity was held pursuant to a decision of the relevant Working Group or the Panel but that such decision does not imply Working Group or Panel endorsement or approval of the proceedings or any recommendations or conclusions contained therein.

IPCC co-sponsorship may be extended to other workshops, seminars or meetings if the IPCC Chairman, as well as the Co-chairmen of the relevant Working Group and, where appropriate, the Co-chairmen of the relevant Subgroup determine in advance that the activity will be useful to the work of the IPCC. IPCC co-sponsorship of such an activity does not convey any obligation by the IPCC to provide financial or other support. In considering whether to extend IPCC co-sponsorship, the following factors should be taken into account:

- whether full funding for the activity will be available from sources other than the IPCC
- whether the activity will be open to government experts as well as experts from non-governmental organizations participating in the work of the IPCC
- whether provision will be made for participation of experts from developing countries and countries with economies in transition
- whether the proceedings will be published and made available to the IPCC in a time frame relevant to its work
- whether the proceedings will:
  - (a) include a full list of participants
  - (b) indicate when and by whom they were prepared
  - (c) indicate whether and by whom they were reviewed prior to publication
  - (d) specify all sources of funding and other support
  - (e) prominently display the following disclaimer at the beginning of the document:

"IPCC co-sponsorship does not imply IPCC endorsement or approval of these proceedings or any recommendations or conclusions contained herein. Neither the papers presented at the workshop/meeting/seminar nor the report of its proceedings have been subjected to IPCC review."

ANNEX 2

TASKS AND RESPONSIBILITIES FOR LEAD AUTHORS, CONTRIBUTORS AND EXPERT REVIEWERS OF IPCC REPORTS AND IPCC GOVERNMENT CONTACTS

1. Lead Authors (LAs)

Function: To produce designated sections addressing items of the work programme on the basis of the best scientific and technical information available.

Comment: Lead authors will typically work as small groups which have responsibility for ensuring that the various components of their sections are brought together on time, are of uniformly high quality and conform to any overall standards of style set for the document as a whole.

The task of lead authors is a demanding one and in recognition of this the names of LAs should appear prominently in the final report. During the final stages of report preparation, when the workload is often particularly heavy and when lead authors are heavily dependent upon each other to read and edit material, and to agree to changes promptly, it is essential that the work should be accorded the highest priority.

The essence of the lead authors' task is synthesis of material drawn from the peer reviewed literature, generated at workshops or submitted by contributors. Lead authors may not necessarily write original text themselves, but they must have the proven technical ability to develop text that is scientifically sound and that faithfully represents, to the extent that this is possible, contributions by a wide variety of experts. The ability to work to deadlines is also a necessary practical requirement.

Principles Governing IPCC Work[2] require LAs to record views which cannot be reconciled with a consensus view but which are nonetheless scientifically or technically valid.

Lead authors may convene meetings with contributors, as appropriate, in their preparations of their sections and to suggest any workshops in their relevant areas to the Subgroup or Working Group co-chairs.

2. Contributors

Function: To prepare technical information in the form of text, graphs or data for assimilation by the lead authors into the draft section.

Comment: Input from a wide range of contributors is a key element in the success of IPCC assessments, and the names of all contributors should be acknowledged in the reports. Contributions are sometimes solicited by Lead Authors but unprompted contributions are positively encouraged.

Contributed material may be edited, merged and if necessary, amended, in the course of developing the overall draft text.

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3. Expert Reviewers

Function: To comment on the accuracy and completeness of the scientific/technical content and the overall scientific/technical balance of the drafts.

Comment: Expert reviewers will comment on the text according to their own knowledge and experience. They may be nominated by Governments, national and international organizations, Working Group Bureaus, Lead Authors and contributors.

4. Government Review

Function: To comment on the accuracy and completeness of the scientific/technical content and the overall scientific/technical balance of the drafts.

Comment: Government review will typically be carried out within and between a number of Departments and Ministries. Countries may convene their own seminars and workshops to review draft reports and advise on comments. For administrative convenience, countries should nominate a single IPCC Government Contact.

Addendum 1 to the IPCC Procedures

(Approved at the Tenth Session of the IPCC, Nairobi, 10-12 November 1994)

The wide international review to which IPCC reports are exposed represents one of the major strengths of the process. The IPCC recognizes, however, that the burden of handling large numbers of review comments fall most heavily upon the Lead Authors and the Working Group bureaux, all of whom have other pressures on their time even apart from the extremely tight deadlines applied by the IPCC process. Since the success of the IPCC depends ultimately upon the co-operation and willing commitment of these scientists, it is essential that all is done to make their task as easy as possible.

The Panel agreed that in any change to be made in the review process, two principles governing the review should be borne in mind. First, the best possible scientific and technical advice should be received so that the IPCC reports can represent the latest scientific findings and be as scientifically credible as is possible. Secondly, a wide circulation (including experts in developing countries) should aim to involve as many experts as possible in the IPCC process.

The Panel agreed that:

1. Each government and participating organization should designate one Focal Point for all IPCC activities as defined in the IPCC Procedures[3], and provide full information[4] on this Focal Point to the IPCC Secretariat. The Focal Point should liaise with the IPCC Secretariat and the appropriate Technical Support Unit (TSU) regarding the logistics of the review process(es). Of particular importance is the full exchange of information.

2. For the 1995 SAR, Working Group I will follow the existing IPCC Procedures concerning Expert and Government review, but will run the two review processes concurrently. The time allocated for review will be extended to at least eight weeks.

3. For the 1995 SAR, Working Groups II and III, already well into the review process, will continue with a two-stage Expert and Government review.

4. The experience of Working Group I in running a concurrent Expert and Government review will be appraised at the Eleventh Session of the IPCC.

Addendum 2 to the IPCC Procedures

Approved at the Eleventh Session (Rome, 11-15 December 1995)

IPCC Procedures for the Preparation of Technical Papers

1. At its Eleventh Session (Rome, December 11-15, 1995), the Intergovernmental Panel on Climate Change adopted by consensus the following procedures for the preparation of Technical Papers.

2. IPCC Technical Papers are prepared on topics for which an independent, international scientific/technical perspective is deemed essential. They:

a. are based on the material already in the IPCC assessment reports and special reports;
b. are initiated: (i) in response to a formal request from the Conference of the Parties to the UN Framework Convention on Climate Change or its subsidiary bodies and agreed by the IPCC Bureau; or (ii) as decided by the Panel;
c. are prepared by a team of authors, including a convening lead author, selected by the IPCC Bureau, in accordance with the guidelines for the selection of lead authors contained in the IPCC Procedures[5];
d. are submitted in draft form for simultaneous expert and government review at least four weeks before the comments are due[6];
e. are revised by the led authors based upon the comments received in the step above;
f. are submitted for final government review at least four weeks before the comments are due;
g. are finalized by the lead authors, in consultation with the IPCC Bureau which functions in the role of an editorial board, based on the comments received; and,
h. if necessary, as determined by the IPCC Bureau, would include in an annex differing views, based on comments made during final government review, not otherwise adequately reflected in the paper.

3. Such Technical Papers are then made available to the Conference of the Parties or its subsidiary body, in response to its request, and thereafter publicly. If initiated by the Panel, Technical Papers are made available publicly. In either case, IPCC Technical Papers prominently state in the beginning :

> "This is a Technical Paper of the Intergovernmental Panel on Climate Change prepared in response to a [request from the United Nations Framework Convention on Climate Change] / [decision of the Panel]. The material herein has undergone expert and government review but has not been considered by the Panel for possible acceptance or approval."

4. The Panel agreed that these procedures should be reviewed in 1997.

APPENDIX A

PRINCIPLES GOVERNING IPCC WORK

Introduction

1. The IPCC shall concentrate its activities on the tasks allotted to it by the relevant WMO Executive Council and UNEP Governing Council resolutions and decisions.

Organization

2. The IPCC Bureau shall reflect balanced geographic representation. IPCC Working Groups and any task forces established by the Plenary shall reflect balanced geographic representation with due consideration for scientific and technical requirements.

3. IPCC Working Groups and any task forces constituted by the Plenary shall have clearly defined and approved mandates and work plans as established by the Plenary, and shall be open-ended.

Participation

4. Invitations to IPCC Plenary, Working Group and task force sessions shall be extended to Governments and other bodies by the Chairman of the IPCC.

5. Experts from WMO/UNEP Member countries or international, intergovernmental or non-governmental organizations may be invited in their own right to contribute to the work of the IPCC Working Groups and task forces. Governments should be informed in advance of invitations extended to experts from their countries and if they wish may nominate additional experts.

Procedures

6. In taking decisions, drawing conclusions, and adopting reports, the IPCC Plenary and Working Groups shall use all best endeavours to reach consensus. If consensus is judged by the relevant body not possible: (a) for decisions on procedural issues, these shall be decided according to the General Regulations of the WMO; (b) for conclusions and adoption of reports, differing views shall be explained and, upon request, recorded.

7. Conclusions drawn by IPCC Working Groups or task forces are not official IPCC views until they have been discussed and accepted by the IPCC Plenary.

8. Invitations to IPCC Plenary, Working Group and task force sessions should be extended at least six weeks in advance.

9. Major reports, basic documentation and other available reports for consideration at IPCC Plenary and Working Group sessions shall be made available by the IPCC Secretariat four weeks in advance, to the extent possible, in all official UN languages. Working papers shall be circulated as far in advance as possible.

10. Interpretation into all official UN languages should be provided for all IPCC and Plenary and Working Group sessions.

11. The sessions of IPCC working Groups and task forces shall be co-ordinated with other international meetings, including sessions of the INC and UNCED Preparatory Committee.

12. These Principles are to be reviewed at least annually and amended as appropriate.

[1] The Panel agreed that definitions of the terms "acceptance" and "approval" should be communicated well to the reader in the IPCC published reports.

[2] See appendix A.

[3] IPCC Procedures for Preparation, Review, Acceptance, Approval and Publication of its Reports.

[4] Name, address, telephone, fax and e-mail

[5] The Procedures state: "Preparation of the first draft of a report should be undertaken by lead authors identified by the relevant Working Group bureau from those experts cited in the lists provided by all countries and participating organizations, with due consideration being given to those known through their publication or work. In sofar as practicable, the composition of the group of lead authors for a section of a report shall reflect fair balance among different points of view that can reasonably be expected by the Working Group bureau, and should include at least one expert from a developing country.

[6] It may be recalled that in the preparation of its contribution to the IPCC Second Assessment Report, Working Group I conducted the expert and government reviews concurrently (see Addendum 1). The time given for expert and government comments was eight weeks.

The following questions were submitted to NASA Associate Administrator for the Office of Mission to Planet Earth on April 18, 1996 for reply by May 2, 1996.

As of June 17, 1996, the Committee on Science had received no reply from NASA.

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*Ranking Democratic Member

April 18, 1996

Dr. Charles Kennel
Associate Administrator, Office of
Mission to Planet Earth
NASA Headquarters
Washington, DC 20546-0001

Dear Dr. Kennel:

On behalf of the Committee on Science I want to thank you for participating in the *U.S. Global Change Research Programs: Data Collection and Scientific Priorities* hearing held March 6, 1996. I appreciate your time and effort in presenting testimony. Your appearance afforded Committee Members an excellent forum to discuss recommendations for the future of this research program.

Enclosed are additional questions for the hearing record, please provide your response to the Committee by no later than May 2, 1996.

Thanks for your help in making this hearing a success.

Cordially,

Robert S. Walker
Chairman

RSW/cf
Enclosure

Questions Submitted for the Record by the Honorable Robert S. Walker Chairman, House Committee on Science

Dr. Charles Kennel
NASA - Office of Mission to Planet Earth

1. In his prepared statement, Mr. Hathaway of the GAO notes that NASA solicited proposals to increase the funded science researchers for Mission to Planet Earth last fall, but that the solicitation limited proposals to analyzing existing data-bases. While the Committee supports maximizing the cost-effective analysis of data already paid for, why didn't NASA do this before starting EOS and why does the solicitation limit the ability of researchers to analyze EOS data?

2. In NASA's past efforts to work with the commercial remote sensing industry, the agency provided significant funding for the construction of the relevant spacecraft. Will the fact that the rising commercial remote sensing industry is paying for the development of new remote sensing satellites with its own money help the agency work better with the private sector?

3. The Land Remote Sensing Policy Act of 1992 gives government agencies the ability to ask the private sector to fly sensors that serve agency purposes on private satellites if the government agency reimburses the private sector for any marginal cost increases associated with doing so. Has NASA approached any private companies that currently operate or are planning to operate satellites to explore such a partnership? If so, which companies has NASA approached? If not, why not, since this would seem to lower government costs?

4. NASA identified 12 potential user groups for MTPE data and products, yet only three of these involve active scientific researchers. Since the purposes of the other groups include land-use planning and agricultural improvements, won't this amount to the government entering the commercial market for providing remote sensing data and applications? The Resources 21 constellation, for example, is specifically targeted towards the agriculture industry. How can NASA fulfill its responsibilities to promote the commercial development of space if it's competing with the private sector and meeting demands that the private sector wants to supply?

5. NASA has informed Congress that it wants to start the Earth System Science Pathfinder program of small satellites to introduce some flexibility and ability to address our science requirements on the basis of changing science. Why wasn't EOS initially designed with this flexibility in mind? If the EOS baseline program is supposed to acquire the needed data in NASA's 24 data sets, then what added value does Pathfinder bring to Mission to Planet Earth?

6. Dr. Ledebuhr's testimony stated that the term, "faster, better, cheaper" can also apply to Mission to Planet Earth (MTPE). He mentioned a mission called Clementine, which

was supported through DoD, as an example validating the national security community's ability to rapidly integrate and launch low-cost satellites using miniaturized sensors. Clementine mapped the moon at a mission cost of less than $100 million. The schedule of Clementine from start to launch was 22 months and it demonstrated that small satellites incorporating state-of-the-art sensor and spacecraft bus technologies could generate scientifically useful data at affordable costs. Dr. Ledebuhr stated in his prepared statement, "It is our contention that the technologies, system engineering approach, and advanced component testing demonstrated in the (Clementine) mission could quickly and affordably be applied to earth monitoring applications." This type of capability could provide USGCRP with an interim data set to better establish long term global change trends as well as generate a global monitoring system that would support a wide range of both civilian and military applications.

Dr. Kennel, how has NASA used the technology gained from Clementine to improve MTPE and its data collection equipment?

7. Given the constraints in both our civil and military space budgets, has NASA explored pooling its resources with the Departments of Defense and Energy to develop the kind of dual-use earth monitoring system that Dr. Ledebuhr described in his testimony?

8. While NASA may have judged the Energy Department's proposed $370 million dollar distributed remote sensing constellation as immature in 1991, the last five years have given us more experience with the relevant technologies and introduced severe budget constraints. Do these developments warrant creating an outside panel of experts to review the DoE concept again?

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April 18, 1996

Dr. Richard Lindzen
Sloan Professor of Meteorology
Center for Meteorology and Physical Oceanography, Room 1720
Massachusetts Institute of Technology
Cambridge, MA 02139

Dear Dr. Lindzen:

On behalf of the Committee on Science I want to thank you for participating in the *U.S. Global Change Research Programs: Data Collection and Scientific Priorities* hearing held March 6, 1996. I appreciate your time and effort in presenting testimony. Your appearance afforded Committee Members an excellent forum to discuss recommendations for the future of this research program.

Enclosed are additional questions for the hearing record, please provide your response to the Committee by no later than May 2, 1996.

Thanks for your help in making this hearing a success.

Cordially,

Bob Walker

Robert S. Walker
Chairman

RSW/cf
Enclosure

Questions Submitted for the Record by the Honorable Robert S. Walker Chairman, House Committee on Science

Dr. Richard Lindzen
Massachusetts Institute of Technology

1. You alluded to the benefits of a healthy and creative scientific community for advancing the state of our knowledge as sometimes being more important than a large government program. Is there anything in the Federal Government's approach to the USGCRP that undermines a healthy and creative science community? Are there any steps that the Federal Government can take to promote a health science community?

2. In your opinion, is the Federal Government funding a wide enough variety of science investigators for the normal scientific process of debating findings to take place?

3. Your prepared testimony states that many of the largest recent advances in our understanding of climate change did not come from any large government program, but from the creativity of individual scientists who exchange findings and theories personally. Do you have any suggestions about steps we can take to use Mission to Planet Earth funding to leverage this characteristic of the scientific process?

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April 26, 1996

CF

Representative Robert S. Walker
Committee on Science
U.S. House of Representatives
Suite 2320 Rayburn House Office Building
Washington, DC 20515-6301

MAY 03 1996

Dear Representative Walker:

The following are my responses to your additional questions.

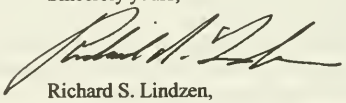
1. The health of climate science is, indeed, undermined by the emphasis on global warming. If global warming is perceived as the basis for support, then the incentives to deal concretely with this part of climate science is, in fact, diminished. What has happened is that atmospheric, oceanic and other scientists have all tended to relate their usual research interests to global warming on the supposition that this problem can sustain their research for the foreseeable future. The Federal Government can promote a healthy science community by emphasizing basic science independent of the concerns for any specific problem and doing more to assure stable and secure support at a defined level regardless of the state of specific environmental issues. Important issues will naturally attract the attention of scientists, but there must be no suspicion that support depends on these issues. Here, the distinction made in the first part of the hearings by the representative of the GAO between programs and scientists becomes particularly relevant. The stable and secure support of scientists is essential to preserving our scientific capacity, and ought to be far less intimately coupled to the support of specific large projects. Projects inevitably assume that a meaningful scientific foundation already exists. In some instances this is justified. However, the earth sciences are in a relatively early stage of development, and prematurely large projects can tend to stifle rather than encourage the necessary free-ranging inquiry by both diverting limited scientific talent toward the projects, and by discouraging the critical assessment of these projects which inevitably constitute interest groups on their own behalf.

2. My impression is that the Federal Government is supporting a very wide variety of scientists. The problem, as I discussed in item 1, is that there is a broad impression that the support hinges on public concern with global warming, the ozone hole, etc. Thus, there is an intrinsic bias against those who would question the bases for the public concerns.

3. The problems with MTPE are somewhat distinct. To a large extent, these problems are described in my original testimony. The EOS portion of the program displays the problems of a program designed in the absence of clear scientific foundations. Lacking well posed questions, it was designed to acquire huge amounts of data in the hope that something measured would prove vital. At least for the foreseeable future, the scale of EOS is probably too large for the size of the relevant scientific communities. With the immense resources associated with EOS, a community was created to support the program as opposed to the program supporting the specific needs of science. The concern over global warming and the subsuming of EOS under MTPE only made more evident the inefficiency of EOS' scatter-shot approach. While NASA has, in a variety of ways, attempted to improve the situation, the heritage of EOS is hard to shed. Nevertheless, NASA's current approach appropriately emphasizes much greater flexibility to respond to new ideas. The important point at this stage is to make sure that there will be a steady flow of new ideas and a constant testing of old ideas. This requires that major projects reserve a relatively small portion of their budgets for free ranging investigations that are not tied to the specific details of the project. It is essential that this relatively small portion be given a protected status so that thinking continues independent of the inevitable budgetary turns which will confront any large project. Thus far NASA has not given adequate attention to this need. Rather, it is the relatively inexpensive theoretical and analytical efforts that receive the least secure support – being treated as unnecessary indulgences rather than the fundamental seed beds for any program. In my experience, program managers have claimed that Congress is incapable of understanding free inquiry. My own suspicion is that it is usually the program managers who have difficulty with free inquiry since it often does not simply fit into existing programmatic boundaries, and, moreover, by virtue of its small expense, adds little to the size of bureaucratic empires. Congress, by acknowledging the importance of free inquiry in a formal manner, can do much to make sure that the best intellectual characteristics of the scientific process remain available to programs. The notion that the least expensive and most fundamental aspects of science should be the most vulnerable ultimately doesn't make sense. As a practical matter, basic research offices should be established within mission agencies. These offices should be independent of specific missions (though, of course, they should focus on broad areas that are at least potentially relevant to missions; i.e., missions associated with global change should probably not be supporting childhood development studies). The existence of such offices is essential if basic research is to have a voice within agency bureaucracies.

I hope the above responses adequately clarify the points I made in my testimony. I appreciate the opportunity to contribute to the efforts of your committee.

Sincerely yours,



Richard S. Lindzen,
Sloan Professor of Meteorology

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April 18, 1996

Mr. Aram Mika
Hughes Aircraft Corporation
Mail Code EO/E1C150
P.O. Box 902
El Segundo, CA 90245

Dear Mr. Mika:

On behalf of the Committee on Science I want to thank you for participating in the *U.S. Global Change Research Programs: Data Collection and Scientific Priorities* hearing held March 6, 1996. I appreciate your time and effort in presenting testimony. Your appearance afforded Committee Members an excellent forum to discuss recommendations for the future of this research program.

Enclosed are additional questions for the hearing record, please provide your response to the Committee by no later than May 2, 1996.

Thanks for your help in making this hearing a success.

Cordially,

Robert S. Walker
Chairman

RSW/cf
Enclosure

Questions Submitted for the Record by the Honorable Robert S. Walker Chairman, House Committee on Science

Mr. Aram Mika
Hughes Aircraft Corporation

1. In your written statement you assert that the current Mission to Planet Earth EOS constellation is a well-balanced design that uses state-of-the-art hardware from all available sources. If that is the case, then why is your parent company, Hughes, protesting NASA's award of the EOS common spacecraft contract to TRW, your corporate competitor? NASA tells us that TRW's proposal was the optimal design in terms of value. Why does Hughes believe that TRW's proposal is not the optimal design?

2. Your statement also says that the EOS spacecraft thoroughly exploit cutting-edge NASA, DoD, and commercial space technologies, but the only evidence of that in your statement is the observation that the MODIS instrument depends on past DoD investments in focal-plane arrays. Your conclusion contradicts the findings of NASA's own *Federal Laboratory Review*, which observed that NASA was not making use of DoD-developed technology in its space technology enterprise, that MTPE was not incorporating advanced technology into its program, and that MTPE suffers from a "not invented here" syndrome. That review only confirmed earlier findings in the National Research Council reports *Improving NASA's Technology for Space Science* and *Technology for Small Spacecraft*, that NASA and MTPE weren't using DoD-developed technologies. Given this conflicting information, on what basis do you assert that the EOS spacecraft exploit cutting-edge technology from DoD? Could you describe specific sensors and satellite systems developed in DoD that are being used in Mission to Planet Earth that would support your conclusion, as opposed to generic technologies originally developed with DoD funding?

3. Recently, NASA and the Jet Propulsion Laboratory have developed a revolutionary active pixel sensor that will enable them to build video cameras about the size of a gambling die. Similarly, the Defense Department's Clementine mission flew a nickel-hydrogen battery weighing half as much as previous models and yet producing twice the energy. Your testimony indicated that sensor and spacecraft size are dictated by the scientific requirements. How do you account for the success of NASA, DoD, and DoE efforts to radically miniaturize sensor and spacecraft technologies? Why don't these successes indicate that the size of sensors and spacecraft components is dictated by a combination of science requirements and the available technology and that new technology is making it possible to build spacecraft an order of magnitude smaller?

HUGHES
AIRCRAFT

Aram M. Mika President
Space Electro-Optics Business Unit

2 May 1996

The Honorable Robert W. Walker
Chairman, Committee on Science
U.S. House of Representatives
Washington, DC 20515-6301

Dear Chairman Walker:

Thank you for your letter of 18 April; it was my pleasure and privilege to appear before the Committee on Science in regard to Mission to Planet Earth. We hope that this key program will proceed apace in order to provide the Nation with important and highly useful earth-observation capability into the twenty first century.

With regard to the three follow-up questions accompanying your letter, I have enclosed my responses for the record.

Thank you again for the opportunity to share some views and perspectives with the Committee.

Sincerely,

Aram M. Mika

Hughes Aircraft Company
2000 East El Segundo Boulevard
PO Box 902, El Segundo, CA 90245-0902
(310) 616-1375

Response to Questions Submitted for the Record by the Honorable Robert S. Walker Chairman, House Committee on Science

by

Aram M. Mika
Hughes Aircraft Company

2 May 1996

[For clarity, the questions as submitted are reproduced below followed by the response.]

Question 1: In your written statement you assert that the current Mission to Planet Earth EOS constellation is a well-balanced design that uses state-of-the-art hardware from all available sources. If that is the case, then why is your parent company, Hughes, protesting NASA's award of the EOS common spacecraft contract to TRW, your corporate competitor? NASA tells us that TRW's proposal was the optimal design in terms of value. Why does Hughes believe that TRW's proposal is not the optimal design?

Response 1: I believe that both my written statement and the basis of Hughes' protest have been misinterpreted.

First, as indicated in the text of your question, my previously submitted comments were directed primarily at the *system architecture* of the EOS program (the "constellation") and at the payload/satellite technology on the EOS-AM1, other current Mission to Planet Earth spacecraft, and the technology potentially available from the companies which competed for the most recent spacecraft award. In this context, both my written and oral remarks indicated that the Mission to Planet Earth constellation of spacecraft represented a judiciously balanced combination of small and medium sized spacecraft, and that the contractor community had used and would continue to use the best available technologies from all sources. I was not referring to any specific payload or satellite design as ultimately submitted in the proposals for the EOS common spacecraft.

Secondly, Hughes' protest of the award of a contract to our competitor (TRW) was based upon perceived irregularities in the source *evaluation and selection process* that led to the contract award. In essence, Hughes protested because we felt that those procedural irregularities led to a flawed evaluation of the competing proposals and ultimately denied NASA the full benefit of competition and the opportunity to achieve the true "best value." Indeed, according to the GAO report submitted in connection with the protest, NASA rated Hughes as "Excellent" in the Mission Suitability category, while TRW was rated as "Very Good."

Question 2: Your statement also says that the EOS spacecraft thoroughly exploit cutting-edge NASA, DOD, and commercial space technologies, but the only evidence of that in your statement is the observation that the MODIS instrument depends on past DOD investments in focal-plane arrays. Your conclusion contradicts the findings of NASA's own *Federal Laboratory Review*, which observed that NASA was not making use of DOD-developed technology in its space technology enterprise, that MTPE was not incorporating advanced technology into its program, and the MTPE suffers from a "not invented here" syndrome. That review only confirmed earlier findings in the National Research Council reports *Improving NASA's Technology for Space Science* and *Technology for Small Spacecraft*, that NASA and MTPE weren't using DOD-developed technologies. Given this conflicting information, on what basis do you assert that the EOS spacecraft exploit cutting-edge technology from DOD? Could you describe specific sensors and satellite systems developed in DOD that are being used in Mission to Planet Earth that would support your conclusion, as opposed to generic technologies originally developed with DOD funding?

Response 2: My written statement cited *many* examples that exploit cutting-edge NASA, DOD, and commercial space spacecraft and sensor technologies. Specifics included:

"... advanced technologies such as graphite-epoxy composites, solid-state recorders, microwave integrated circuits, solid-state transmitters, a capillary pump thermal system, precision pointing, and on-board spacecraft navigation have all been incorporated on the EOS-AM1 spacecraft." Payload technologies cited in my statement included not only focal-planes but advanced signal processing and materials as well.

This information is based upon first-hand experience in the industry over the past twenty years during which I have observed (and exploited) the interchange of technology among DOD, NASA and commercial programs. In the spacecraft arena, the similarity/commonality between the spacecraft for the Defense Meteorological Satellite Program (DMSP) and the Advanced Tiros-N series (now known as the NOAA series) illustrates the two-way flow of technology. More recently, the new Tracking and Data Relay System Satellite (TDRSS) currently being developed is based upon Hughes' highly successful HS-601 commercial communication satellites. In the sensor arena, for example, radiative cooler technology pioneered in our civil-space business is being used on DOD's Space and Missile Tracking System (SMTS) program, while electronics and signal-processing technology from our DOD product line is being exploited in the design and fabrication of the high-speed multiplexer for our Landsat 7 sensor for NASA. This free exchange between DOD, NASA and commercial technologies is easy to see from within the industrial community that is engaged in all three markets, but this may not be so visible from other vantage points outside of this experience base.

As for direct application of DOD technologies, this makes eminent sense (and is quite common) at the subsystem level where the functionality is identical for either DOD, NASA or commercial applications. For example, spacecraft subsystems such as momentum wheels, solar panels or star trackers and sensor subsystems such as focal-plane modules, servo torquers and encoders, signal-processing subsystems and the like are all freely exploited. At the complete sensor or system level, the specific application or mission dictates the overall design, and the substitution of DOD for NASA sensors becomes more complex.

There are indeed *some* areas where there is significant mission commonality to support complete dual-use designs (such as for meteorological satellites), and we strongly encourage such economies and efficiencies. In this regard, the joint DOD/NOAA/NASA "convergence" program for the next generation National Polar-Orbiting Operational Environmental Satellite Program (NPOESS) was most encouraging, although the program has apparently been delayed.

For most other applications, however, the mission requirements for DOD and Civil Space applications for electro-optical sensors are strikingly different, and this is why it is unreasonable to expect widespread direct substitution of DOD sensors for NASA applications and vice versa. For example, the spatial, spectral, radiometric and temporal resolution and coverage requirements for tracking missiles or terminal guidance, differ radically from those needed for earth observation or planetary science.

Question 3: Recently, NASA and the Jet Propulsion Laboratory have developed a revolutionary active pixel sensor that will enable them to build video cameras about the size of a gambling die. Similarly, the Defense Department's Clementine mission flew a nickel-hydrogen battery weighing half as much as previous models and yet producing twice the energy. Your testimony indicated that sensor and spacecraft size are dictated by the scientific requirements. How do you account for the success of NASA, DOD, and DOE efforts to radically miniaturize sensor and spacecraft technologies? Why don't these successes indicate that the size of sensors and spacecraft components is dictated by a combination of science requirements and the available technology and that new technology is making it possible to build spacecraft an order of magnitude smaller?

Response 3: Both my oral comments (e.g., ". . the scale follows from the physics and technology") and written statement indicated that the size of sensors and spacecraft components is indeed dictated by a combination of both science and technology. The following excerpt and accompanying figure from pages 5 and 6 of my statement convey this point (emphasis added for clarity):

. . These tradeoff studies address the design alternatives that can produce the required measurements, within the constraints set by fundamental physics, ***technology state-of-the-art****, and cost. Within these bounds, designers work to minimize size, mass and power requirements. The process does not proceed in a vacuum: the engineers work iteratively with the scientific community to challenge requirements that are driving cost, size, mass and power so that science utility per dollar is effectively optimized; this is precisely the process that was used to develop the current suite of payload instruments. In short, size and mass flow from functionality, as illustrated on the next page.*

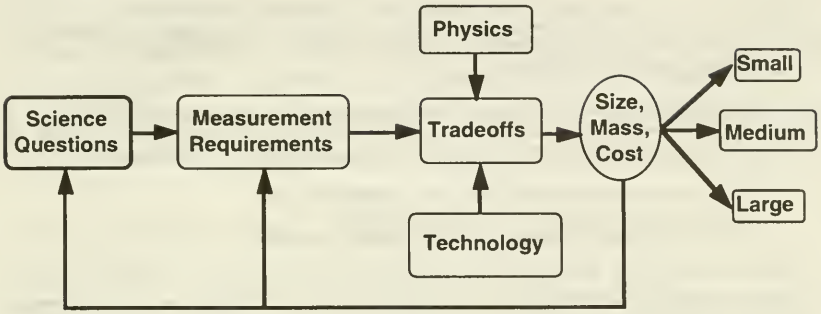

Figure 1. Size Follows Functionality

Another excerpt from my written statement amplifies on the issue of technology:

Strategies for the Future: Technology Insertion and Data Continuity

Although the current EOS instruments are thoughtfully designed, ***continuing improvements in technology can and will influence the design tradeoffs****, so there must be an effective mechanism for periodically revisiting these tradeoffs and incorporating new technologies that can enhance capability or reduce cost. This introduces a classic cost tradeoff: there are significant nonrecurring engineering costs associated with developing new instruments, so that the cost of developing the first of a series of new instruments is almost invariably higher than simply building another copy of an existing design. Yet, newer sensor designs could offer savings in total system cost, if size, mass and power reductions permit corresponding reductions in spacecraft and launch vehicle size -- but the design of the smaller spacecraft needed to realize these system-level savings requires another nonrecurring investment , and so it goes at many levels.*

In essence, there are competing strategies for effecting economies. On the one hand, the most powerful economic strategy is to produce many copies of the same design, thereby deriving economies of scale from quantity production and amortization of nonrecurring development costs over many units. On the other hand, advances in technology will eventually change the cost/capability equation enough to overwhelm the economies of scale. Accordingly, an effective strategy must balance these countervailing trends by embracing a methodical strategy that captures some economies of scale by producing several copies of a particular design, and then periodically introducing 'block changes' that exploit advances in technology -- perhaps on every second series of satellites. Indeed, this strategy has been used by other satellite programs, and its adoption is not accidental.

Data continuity introduces another dimension to the technology strategy. A stable set of well-calibrated, reliable measurements is central to the Global Change Research Program. Indeed, much effort has been expended to design instruments that will be stable enough to ensure that we are truly measuring changes in the earth and its environs, rather than instrument artifacts and instabilities. Introducing new instruments will undermine continuity and confidence in the measurements. Yet, there are serious problems in attempting to field a particular set of instruments in perpetuity. Technological obsolescence will eventually make it infeasible to even reproduce a given set of instruments due to diminishing availability of the specific components and skills that

are associated with a particular design. Twenty years is probably the outside limit for any one design. In fact, some space instruments have been in 'production' for nearly this interval, but closer examination would reveal that they have been continually upgraded to surmount some of the parts availability problems cited above.

The complex challenge of technical renewal, while maintaining data continuity and quality, can best be addressed by embracing a concept that we might call dynamic continuity. Specifically, the quality and continuity of measurements must be transparent to three levels of changes:

- *Between successive flights of the same instrument design*
- *Between successive generations of instruments*
- *Between similar instruments fielded by different countries*

Dynamic continuity can be achieved via a strategy that encompasses a rigorous calibration program, utilizing both in-orbit and in-situ measurements, and the discipline to adopt an approach that ensures overlapping measurements between successive generations of instruments over a sufficient interval to ensure accurate cross-calibration. In many respects, NASA did this very well in the Landsat 4-5 era, where the new 'experimental' Thematic Mapper instrument was carried alongside the existing 'operational' Multispectral scanner.

This same basic approach can and should be carried forward as a technology insertion strategy, although it is not strictly necessary to carry the old and the new simultaneously on the same spacecraft. Indeed, smallsats become an ideal vehicle for the development and introduction of new technology in a fashion that does not introduce risk into the mainstream scientific-measurement program. Specifically, new payload instruments, developed in parallel with EOS and flown on smallsats (perhaps in formation with the EOS spacecraft) would be an excellent approach for establishing the validity and intercomparability of the new and old measurements. This overlap also provides an opportunity to develop and prove the algorithms for reducing and analyzing the data from these new payloads and to provide an orderly transition as these experimental instruments, first flown on smallsats, become the next-generation mainline instruments on subsequent spacecraft.

Another powerful aspect of this approach is that it encourages pursuit of high-risk, high-payoff technologies. By conducting the development off-line without risk to an operational mission, fear of failure does not become an overriding principle that stifles innovation. Moreover, the development protocol for such technology demonstrations can be less formal and expensive -- a "skunk works" operation tailored to the needs of an experimental program.

GAO's Response to Questions Submitted for the Record by the Honorable Robert S. Walker Chairman, House Committee on Science

1. **QUESTION: Based on the FY96 budget request and any available information on out-year spending associated with the FY97 budget are there sufficient resources identified in the NASA budget to fund both the Pathfinder program and an expansion of the funded science community for Mission to Planet Earth?**

ANSWER: NASA has not identified sufficient resources to fund both Earth System Science Pathfinder missions and an expansion of the Earth Observing System (EOS) research community. The administration requested $20 million for Pathfinder for fiscal year 1997, and projected budgets of $30 million in 1998 and $75 million for each year thereafter to 2001. NASA intends to fund this program from future savings generated by lowering costs of other parts of the Mission to Planet Earth program. Similarly, NASA intends to rely on such savings to expand the EOS interdisciplinary research community beyond the 29 teams it currently funds. To date, NASA has not identified the specific sources of these potential future savings, although in general, NASA hopes to lower Mission to Planet Earth program costs through the use of advanced technology and increased collaboration with other agencies, international partners, and the commercial sector.

2. **QUESTION: In response to external, internal and Congressional reviews of Mission to Planet Earth, NASA has taken steps to initiate the Earth System Science Pathfinder program to make data collection more flexible than EOS and to make better use of commercial and foreign sources of data. Is NASA effectively funding additional scientific researchers to examine the data from these additional sources, or is NASA simply throwing more data at the same number of principal investigators?**

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WILLIAM P. LUTHER, Minnesota

*Ranking Democratic Member

April 18, 1996

Dr. John Christy
Earth Systems Science Laboratory
University of Alabama at Huntsville
Huntsville, AL 35899

Dear Dr. Christy:

On behalf of the Committee on Science I want to thank you for participating in the *U.S. Global Change Research Programs: Data Collection and Scientific Priorities* hearing held March 6, 1996. I appreciate your time and effort in presenting testimony. Your appearance afforded Committee Members an excellent forum to discuss recommendations for the future of this research program.

Enclosed are additional questions for the hearing record, please provide your response to the Committee by no later than May 2, 1996.

Thanks for your help in making this hearing a success.

Cordially,

Robert S. Walker
Chairman

RSW/cf
Enclosure

Questions Submitted for the Record by the Honorable Robert S. Walker Chairman, House Committee on Science

Dr. John Christy - University of Alabama at Huntsville

1. You mentioned that one of the sensors you were using to accumulate temperature data had almost failed recently. Are we overly dependent on these two sensors to collect this data?

2. Does the EOS baseline program contain robust support for the types of microwave sounders that you are using?

3. What steps can the Federal Government take to ensure the reliable continuity of the microwave sounder data set?

UAH
The University of Alabama in Huntsville

Atmospheric Science Department

Huntsville, Alabama 35899
Phone: (205) 922-5754
Fax: (205) 922-5755

29 April 1996

RECEIVED
MAY 0 2 1996
Committee on Science

Hon. Robert S. Walker, Chairman
Committee on Science
Suite 2320 Raybum House Office Bldg.
Washington DC 20515-6301

Dear Rep. Walker:

I wish to thank you for the invitation to provide input for the House Science Committee through the hearing on *U.S. Global Change Research Programs: Data Collection and Scientific Priorities* (6 March 1996). Enclosed are my responses to your follow-up questions. By these responses, I wish to convey to you some sense of concern that our ability to maintain our research program in Huntsville is threatened by general cuts in basic science as well as targeted cuts to Earth Science research at Marshall Space Flight Center and UAH.

The opportunity to participate in the Hearing was especially important to me as I saw the MSU data featured quite prominently by most panel members. We hope to continue as best we can in providing the country and the world with the highest quality atmospheric temperature data available today so that we may truly know how the climate is behaving.

Sincerely,

John R. Christy
Associate Professor
Atmospheric Science Department

Responses to Follow-up Questions to Dr. John R. Christy

1. **You mentioned that one of the sensors you were using to accumulate temperature data had almost failed recently. Are we overly dependent on these two sensors to collect this data?**

In 1993, two satellites, NOAA-11 and NOAA-12, were in orbit providing data for NWS operations as well as our MSU global temperature climate studies. One of these, NOAA-11, was drifting in orbit so badly that within a year we knew we could not calibrate the data for long-term studies. Thus we would have only NOAA-12 on which to rely. NOAA-11's replacement, NOAA-13, was launched in late 1993. However, due to an electrical problem, the entire spacecraft was lost one week after achieving orbit. NOAA-14 was readied for launch to replace the defunct NOAA-13 spacecraft. After NOAA-14 achieved orbit in December 1994, its MSU's rotating mirror ceased to rotate, rendering the MSU of no value. In early 1995, it appeared we had a major problem since NOAA-11 had already been decommissioned (it was fairly useless at that point anyway) and NOAA-12 was aging. If a problem were to develop with NOAA-12, we would cease to have had any MSU data at all.

After considerable effort, the operations staff at NOAA was able to restart the NOAA-14's MSU on 1 April 1995. We have received data continuously since that time for both NOAA-12 and NOAA-14. We are mindful however that NOAA-12 is performing beyond its intended lifespan and that NOAA-14 has already failed once. NOAA-14 contains the last MSU instrument intended for operations. A flight-certified copy of the MSU is at JPL and could possibly be used in an emergency if current MSUs or future AMSUs fail. We have to this point had considerable luck on our side in developing the MSU data set - and we are completely dependent on the current two orbiters.

The next polar orbiter will have a new Advanced MSU (AMSU) which will require us to invest considerable time to develop a method to append AMSU data to the current MSU data in a consistent manner.

2. **Does the EOS baseline program contain robust support for the types of microwave sounders that you are using?**

The EOS AM platform does not contain microwave sounder capabilities. The EOS PM platform is scheduled to carry an AMSU, and would therefore be supportive of our microwave research. The NOAA polar orbiters, used for operational forecasts, should continue to carry microwave sounders at least through 2025.

3. **What steps can the Federal Government take to ensure the reliable continuity of the microwave sounder data set?**

Because the MSU data are utilized in a wide diversity of applications, our small group in Huntsville is unable to accommodate all of the requests for special studies and at the same time continue our own research on producing new and better products. We are often called upon to provide specialized information and expert testimony for various agencies and climate assessment consortia which place considerable time pressures upon us - and for which we receive no funds. Our workload is steadily increasing. We believe our effort would provide continued and enhanced benefits to society if the following were to occur.

1. **Provision for baseline funding for research personnel and graduate students.** This, of course, would be achieved through a legitimate peer-reviewed process, but one that falls outside of the two- to three-year funding cycle format.

2. **Provision of on-site computing and data storage facilities.** Our present computing infrastructure (MSFC/DAAC) has been scheduled for elimination. This will definitely threaten our ability to continue our most basic data analysis.

Regarding the satellite program in general, the quality of the MSU data would be greatly enhanced if the following requirements could be met.

1. **Hold polar orbiters to a strict equatorial crossing time (no drift).**

2. **Provide at least one year of overlapping observations between newly launched and retiring spacecraft.** This insures successful intercalibration.

3. **Maintain at least two functioning MSUs in orbit at any time.**

4. **Be prepared to launch ,on short notice, the final MSU copy if an emergency develops.** This would require building a small spacecraft which would be launched on a small rocket (total cost < $20 million).

ROBERT S. WALKER, Pennsylvania, CHAIRMAN

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WILLIAM P. LUTHER, Minnesota

*Ranking Democratic Member

April 18, 1996

Dr. Eric Christensen
Director, Government Marketing
EarthWatch Inc.
1900 Pike Road
Longmont, CO 80501

Dear Dr. Christensen:

On behalf of the Committee on Science I want to thank you for participating in the *U.S. Global Change Research Programs: Data Collection and Scientific Priorities* hearing held March 6, 1996. I appreciate your time and effort in presenting testimony. Your appearance afforded Committee Members an excellent forum to discuss recommendations for the future of this research program.

Enclosed are additional questions for the hearing record, please provide your response to the Committee by no later than May 2, 1996.

Thanks for your help in making this hearing a success.

Cordially,

Robert S. Walker
Chairman

RSW/cf
Enclosure

Questions Submitted for the Record by the Honorable Robert S. Walker Chairman, House Committee on Science

Dr. Eric Christensen
Earthwatch Inc.

1. Your testimony made it clear that the commercial remote sensing industry is focusing on meeting the technical requirements of non-government data users because the industry wants to meet its customer demand. I understand that Earthwatch would consider some changes to its satellites to meet a government demand for scientific data if the government sought to purchase space science data directly. Do you think other commercial data suppliers would also consider making these changes?

2. Could you please explain the difference between Earthwatch's approach to sensor calibration and NASA's approach? How might Earthwatch consider changing its approach to calibration to meet requirements NASA might have as a purchaser of scientific data?

3. Past government investments in communications satellite technology provided a return to the taxpayers in the form of a private communications industry that invested its own money in new capabilities and provided new services to the government at a price lower than the cost of the government procuring the hardware itself to provide these services. Do you think that this model offers any lessons about the future of the commercial remote sensing industry and the potential return to taxpayers that we might expect from continued growth of the commercial remote sensing industry?

EARTHWATCH
Incorporated

FAX

To : Eric Sterner Date : **May 10, 1996**

From : Kristi Smith/Eric Christensen

Fax: 202 225-6415

Re : Pages. : 5

Here is the reply you were looking for, sorry for the delay in response. If it doesn't come through well please let me know and I will re-send it. My number is 303 682-3891.

Kind Regards

Kristi Smith

1900 Pike Road, Longmont, Colorado USA 80501-6700
Tel: 303.682.3800 Fax: 303.682.3848

**Answers Submitted to the Record by Dr. Eric Christensen, EarthWatch, Inc.
Responding to Questions from
The Honorable Robert S. Walker, Chairman, House Committee on Science**

1. *Your testimony made it clear that the commercial remote sensing industry is focusing on meeting the technical requirements of non-government data users because the industry wants to meet customer demand. I understand that EarthWatch would consider some changes to its satellites to meet a government demand for scientific data if the government sought to purchase space science directly. Do you think other commercial data suppliers would also consider making these changes?*

Before responding to the question, one point needs clarification. In our testimony, EarthWatch sought to distinguish "Science" versus "Commercial" requirements. In this context, we may have used the term "commercial" too broadly. Our definition of "commercial" not only included the private sector, but local and state governments, as well as the federal civil and defense sectors worldwide. Perhaps a better distinction would have been to divide the market into the "research" versus "operational" sectors.

EarthWatch and other commercial satellites have been specifically designed to meet a broad cross-section of requirements from both the private and government markets, such as spectral continuity with the Landsat Thematic Mapper and SPOT satellites, high spatial resolution, high positional accuracy, frequent revisit, large area coverage, easy ordering and quick product delivery. Even though commercial providers like EarthWatch have emphasized practical applications, the new satellites can also make important contributions to scientific research, especially in three of the major areas of global change research: *Atmosphere, Oceans, and Land.*

At present, EarthWatch and other commercial providers are primarily focused on addressing commercial and civil mapping needs, and do not for the moment have plans to incorporate government science requirements into our systems. On the other hand, the incremental cost to EarthWatch of including a capability to collect data of scientific interest is probably not large in most cases. Add-on capabilities such as on-orbit absolute calibration (Question 2), other spectral bands (e.g. middle and thermal infrared), finer spectral wavelength ranges, other sensors, etc. could be incorporated into our satellites, often at far less cost than launching them on government platforms.

Although EarthWatch cannot speak for our competitors, we expect they would evaluate any proposal from the government on the same terms as EarthWatch: does it make good business sense? Issues would include cost, potential market, schedule impact, technological complexity and risk, as well as the benefits of establishing a solid business relationship with the government program. Obviously, any commercial firm would be interested in some type of arrangement where the government would either (1) pay for the payload or (2) guarantee a data purchase that would at least ensure a recovery of implementation costs. The option also exists for the private sector to quickly launch a series of low cost smallsats exclusively carrying science payloads, rather than sharing space with commercial sensors.

EarthWatch believes that there are a number of innovative strategies for structuring business relationships between the government and the commercial earth imaging sectors. As far as EarthWatch is concerned our "door is wide open" to discussions with all government science programs. We eagerly await their reply.

2. *Could you please explain the difference between EarthWatch's approach to sensor calibration and NASA's approach? How might EarthWatch consider changing its approach to calibration to meet requirements NASA might have as a purchaser of scientific data?*

EarthWatch satellite sensors will be calibrated using known targets in the laboratory before launch. Relative calibration (pixel-to-pixel) will provide accuracies of about +/- 0.25% and absolute accuracies of about +/- 5%. Over the life of the satellite, relative calibration on-orbit will be better than +/- 2%, more than sufficient for most commercial and civil applications.

From what we understand, NASA's more stringent scientific requirements will necessitate that absolute calibration be performed on-orbit, using calibrated targets on the EOS spacecraft. EarthWatch does not currently plan on-orbit absolute calibration because of cost and little market demand. Potentially, EarthWatch could use ground-based measurements after the launch of the EarlyBird and QuickBird satellites to approach on-orbit calibration accuracies.

A much more preferable and cost-effective option would be to incorporate on-orbit absolute calibration equipment in our future spacecraft (possibly either EarlyBird II or the QuickBirds). This would provide NASA more assurance that we could meet their performance specifications. In turn, EarthWatch would need some assurance from NASA that we could recover our investment costs (see question 1).

We expect to have all four planned satellites on orbit by mid 1998. Since time is growing short, we would welcome discussions with NASA as soon as possible.

Reply to Question # 3

3. *Past government investments in communications satellite technology provided a return to the taxpayers in the form of a private communications industry that invested its own money in new capabilities and provided new services to the government at a price lower than the cost of the government procuring the hardware itself to provide these services. Do you think that this model offers any lessons about the future of the commercial remote sensing industry and the potential return to taxpayers that we might expect from continued growth of the commercial remote sensing industry?*

As with the development of the communications satellite technology, there is a significant heritage of past federal government investments in technologies (e.g., smallsat bus platforms, sensors) that laid the technical foundation for EarthWatch's commercial space imaging business. In addition, we are using private investment to leverage these technologies into what our investors believe will be a robust industry that will generate new markets and jobs and drive down the overall costs of accessing

satellite imagery.

Another dual-use model worth examining is the emergence of the Global Positioning Satellite (GPS) industry. Originally developed as a military system for providing soldiers with precise tracking and navigation capabilities, GPS was opened to worldwide civilian applications as well. During the decade since the decision to open the system to civil use was made, an American-led multi-billion dollar GPS industry has emerged. The end result is that the government now has access to commercial GPS equipment that is at least two orders of magnitude less costly then the original military procured hardware, as well as access to a multitude of innovative software and hardware applications developed on a commercial basis. The existence of a commercially robust GPS sector is also recognized as a critical augmentation to the government's objective of establishing the US GPS system as the de facto international standard. Likewise, the commercial satellite imaging industry will generate new jobs and markets while developing low-cost, innovative software and hardware, and commercial off-the-shelf applications tools. This will provide the government with the opportunity for greater choices and creative procurement strategies vis-à-vis the market-driven private sector.

Two additional lessons can be drawn from the emergence of both the communications satellite and GPS industries. As part of the rapidly advancing information technology (which also includes the commercial space imaging industry), it is important that the government establish effective liaison with the earth imaging sector to ensure that its procurement efforts remain current with the latest product offerings, (Given the time it sometimes takes government to develop and implement a major procurement, there is always the danger of locking into a software or hardware solution that will be quickly outdated by the time the contract is carried out.) Finally, it is critical that a mutually satisfactory strategy for protecting the intellectual property rights of commercially provided imagery products be worked out between industry and government. There is often a conflict between industry's need to control the distribution of proprietary imagery and the government's desire for complete and unfettered distribution rights. As EarthWatch has testified previously before this Committee, we believe that the site license approach used in the software industry provides a potential model for adoption by the government.

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April 18, 1996

Dr. Peter Castruccio
Ecosystems International, Inc.
PO Box 225
Gambrills, MD 21054

Dear Dr. Castruccio:

On behalf of the Committee on Science I want to thank you for participating in the *U.S. Global Change Research Programs: Data Collection and Scientific Priorities* hearing held March 6, 1996. I appreciate your time and effort in presenting testimony. Your appearance afforded Committee Members an excellent forum to discuss recommendations for the future of this research program.

Enclosed are additional questions for the hearing record, please provide your response to the Committee by no later than May 2, 1996.

Thanks for your help in making this hearing a success.

Cordially,

Robert S. Walker
Chairman

RSW/cf
Enclosure

Questions Submitted for the Record by the Honorable Robert S. Walker Chairman, House Committee on Science

Dr. Peter Castruccio
Ecosystems Inc.

1. Your testimony concludes by noting the importance of funding researchers to analyze the data gathered by Mission to Planet Earth. Do you think using some surface-based sensors instead of some EOS sensors for Mission to Planet Earth to collect data would lower data collection costs and free up some funding for more scientists?

2. Are there any particular space-based Mission to Planet Earth sensors that you would recommend replacing with surface-based systems?

Replies to Questions on Mission to Planet Earth

Submitted to

The Committee on Science

US House of Representatives

by

Dr. Peter Castruccio

President, Ecosystems International, Inc.

May 8, 1996

QUESTION NO. 1. Your testimony concludes by noting the importance of funding researchers to analyze the data gathered by Mission to Planet Earth. Do you think using some surface-based sensors instead of some EOS sensors for Mission to Planet Earth to collect data would lower data collection costs and free up some funding for more scientists?

REPLY

Data collection by surface sensors is expected to drastically reduce EOS program costs. It will also significantly enhance the quality of the data.

Rationale

Let us begin with a bit of definition: what do we mean by surface-based sensors? We define these as measuring devices that are located at or near the earth's surface and that are deployable via normal, non-space means. This includes devices located on the land's surface such as raingages, streamflow gages; on the ocean's surface, such as current-measuring buoys; beneath the surface of land and sea, such as soil humidity sensors, subsurface temperature sensors; and within the atmosphere, such as wind-measuring balloons, airborne air samplers.

Let us speak first to the issue of **performance**. As a general rule, remote sensors operate best in accomplishing direct imaging functions, such as mapping of the earth's surface, or viewing the tops of the clouds. They also do a good job in measuring sea surface temperature, and temperatures of the top layers of the atmosphere.

Remote sensors typically perform worst when asked to quantify phenomena by means of indirect measurements. An example is offered by water pollution. One can infer its presence from afar by

sensing the water's color: yet as to which pollutant is present, only sampling on the spot will provide an accurate answer. The reduced performance of indirect sensing results from experimental findings and is supported by theoretical reasons.
In indirect sensing, the process chain proceeds from the phenomenon to be measured--e.g., solution of a polluting substance in water--to an intermediate phenomenon--e.g., light scattering by the polluting substance--to emission of light energy, visible by the sensor. Theory tells us that every time energy is thus transformed, there follows a corresponding loss of information. Thus, in the example given, the direct measurement of the polluting solutes is bound to provide more exact information than its indirect, remotely sensed counterpart.

The constructs whereby one attempts to translate the results of remote measurements into the mechanisms underlying the actual phenomena are known as "models". Decades of effort and much money have been spent in attempting to develop models correlating remotely sensed signals with phenomena actually occurring in nature. In the earth sciences and resources areas, despite this outpouring of effort and treasure, not infrequently resulting in intricate engineering "contortions", results have been disappointing, and not in my opinion worth the money: especially in view of the fact that in many cases answers were plainly available from surface measurements (whose use was however considered taboo, on the grounds of "technology too unsophisticated, must all be done from space"). Much of the modeling effort is akin to attempting to thread a needle while wearing boxing gloves, instead of simply removing the latter.

In conclusion, other than in the case of properties amenable to direct imaging, most phenomena occurring at or near the earth's surface can be measured by surface-based sensors more precisely than from remote sensing.

Analogous observations hold for measurements within the atmosphere.

Subsurface features, for example undersea currents, cannot in general be detected by remote sensors: or, at best, can be discerned only by indirect measurements operating, imperfectly, in conjunction with complex models. Microwave radar does penetrate soil, but only down to a limited depth - and then only if the soil is dry. Microwaves do not penetrate water to any significant degree.

Where space systems truly shine is in the collection and relaying of data. By virtue of their altitude, satellites dominate large areas of the earth's surface, and are thus able to gather data issuing from widely dispersed surface sensors--thus providing information whose collection would otherwise be considerably more difficult and costly. Several such data collection systems are currently operational.

Table 1 estimates the feasibilities of, and compares the accuracies achievable respectively, by typical space and surface measurements, such as are proposed for the EOS project. The scoring is assigned points from 0 (measurement not feasible within the current state of the art) to 10 (measurement accuracy limited only by the sensor's characteristic). We notice the preponderant weight of the quality of surface versus that of spaceborne remote measurements: in this selected list, the average quality of surface-based measurements turns out to exceed by almost four times the quality of space-derived, remotely sensed measurements.

Turning now to the **financial** issue, data collection by surface- based, in lieu of spaceborne, sensors can be expected to drastically reduce costs, possibly by up to one order of magnitude.

TABLE 1

COMPARISON OF PERFORMANCES BETWEEN SURFACE AND SPACEBORNE REMOTE SENSORS FOR VARIOUS PHENOMENA PROPOSED FOR THE EOS PROGRAM.*

Phenomenon	Surface Sensor	Spaceborne Remote Sensor
Sea surface currents	10 (buoy)	2
Sea subsurface currents	8 (buoy)	0
Surface winds	8 (anemometer)	2-3
Seawater salinity	9 (probe/lab. sample)	0
Algal bloom precursors	8 (lab. sample)	0
Algal bloom presence	8 (lab. sample)	6-7 (if large)
Sea surface temperature	10 (thermometer)	10
Sea subsurface temperature	8 (thermometer)	0
Dissolved pollutants	8 (probe/lab. sample)	0-1
Forest fire propensity	8 (in situ inspection)	3
Rainfall on surface	8 (pluviometer)	2-3
Streamflow	8 (streamgage)	0
Crop/Vegetation status	7-8 (visual inspection)	2-3

*At current state of the art

Score: 0 = not possible at present
10 = best possible within state of the art

A few figures will serve to clarify and quantity this point. An unsophisticated ocean-going buoy, capable of continuously measuring sea current plus another "simple" parameter such as temperature, costs around $2,500, including deployment, and lives about 18 months (the sensing of additional parameters on the same buoy costs approximately $1,500 more per parameter). Existing satellitic data collection and relay systems such as ARGOS, charge $5 per day per buoy (regardless of the number of sensors) to collect and convey the data to any designated user; and an additional $5 to provide the buoy's location. The yearly cost of one such buoy - satellite combination, including the cost of the equipment plus that of processing the data, thus lies between $5,000 (for two measurements) and $6,000 (for three measurements).

In the case of large, complex buoys, capable of measuring surface and subsurface temperatures, current, winds, rainfall etc., and lasting between 18 and 24 months, the yearly cost would amount to approximately $16,000 per buoy.

In the case of fixed sensors, such as land-based gages and moored buoys, whose position is known and thus needs not to be measured, NOAA's GOES satellite provides the data functions for free, thus saving the $5.00 daily fee charged by ARGOS. The attachment, to these types of sensors, of a data transmitter capable of reaching the satellite would cost on the order of $500 to $1,500 per group of sensors sited on the same platform.

It is important to remember that a large number of such sensors are **already in place--paid for by the respective host countries**.

What is the order of magnitude of the costs involved in such a surface-based system? Let us take as example one of NOAA's currently deployed buoy systems. The WOCE (World Ocean Circulation Experiment) comprises a total of 800 or so drifing buoys, separated

by about 300 nautical miles (5° Latitude x 5° Longitude, or 550 Km at the equator). This means that each buoy samples an area of 550 Km x 550 Km, or 300,000 square kilometers.

To cover the entire surface of the oceans, comprising 375 million square kilometers, we would require a total of about 1,250 such buoys. At a unit cost of $6,000 per buoy-year, the yearly bill would aggregate to some $7.5 million[1]. Plus, of course, overhead expenditures. Or about one percent of the costs of the EOS system. Very similar computations hold for the case of land-based sensors.

Let me illustrate the role of surface sensing by exemplifying a system for predicting algal blooms, designed by my company some years ago.

In July of 1989, a massive algal bloom, covering some 2,000 square miles, developed in the upper Adriatic sea: repulsive-looking, viscid mats of vegetal matter reached the sea's western shore, below Venice, coating with slime some one hundred miles of prime beach. In high summer, this region is heavily frequented by tourists, largely from Germany and Northern Europe. Damage to the tourist trade from cancellations of visits and early departures of clients was estimated by local authorities to aggregate between $3 and $5 billion. These authorities wanted to be able to foresee the reoccurrence of such untoward events.

Sure enough, we could "see" the bloom from remote sensing satellites--but only after the fact, when the algae had bloomed and the damage had already been done.

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[1] Costs courtesy of Mr. Mark Bushnell, NOAA Global Drifter Program

Satellite imagery supplied us no clue whatever for predicting the advent of the bloom. The reason is that the formation of algal blooms requires a priori the simultaneous occurrence of certain concentrations of fertilizing chemicals (nitrogen, phosphorus, vitamin B12, etc.), plus sufficiently high water temperatures, very calm waters, and the presence of an algal "seed". None of which phenomena are observable remotely, with the possible exception of the calmness of the waters, detectable via a costly satellite altimeter--or, just as well, by surface-based observation via simple sensors or even through the naked eyeball.

These "invisible" parameters are however conveniently measured by biochemical analysis of the seawater. Our design thus featured motorboats, ploying pre-established patterns, equipped with low-cost Loran positioning systems to determine their location, collecting small samples of water and carrying them to on-shore analysis laboratories. Should the samples indicate the simultaneous presence of the precursor parameters indicated above, a "yellow alarm" would have been triggered, denoting to local authorities that they could begin the undertaking of remedial measures.

In its final design, the entire forecast system consisted of three motorboats, easily and economically collecting samples during the critical June-July period over a fairly wide area, equivalent to that of the State of Maryland.

QUESTION NO. 2. Are there any particular space-based Mission to Planet Earth sensors that you would recommend replacing with surface-based systems?

REPLY

Several EOS sensors appear replaceable by surface-based systems. Additional EOS sensors appear redundant with existing and near-future US and foreign, earth and atmosphere observation satellites. Hence, most of the EOS space system appears to be replaceable.

Rationale

Let me broaden my answer somewhat, by noting that approximately 50 civilian earth observation satellites are either currently flying or are proposed for launch between now and 2007. Of these:

About 40 are near-term, either currently operating or scheduled to fly by 2000

Approximately 7 are commercial

Some 15 are US, the remainder foreign. Among the launching countries are India, Japan, France, Germany, Canada, Israel, China, Brazil, Russia--plus the European Space Agency.

Particularly noteworthy is Boeing's proposed Resource 21 system, whose characteristics of coverage and repeat timing closely approach those of the MODIS sensor--touted as the centerpiece of EOS--but whose acuteness of vision (spatial resolution) is two orders of magnitude sharper. Furthermore, the system would be funded by private industry rather than by the US taxpayer.

Additionally, several meteorological and upper atmosphere observing satellites are planned for the same time frame.

The aforementioned observation satellites are redundant with a number of EOS sensors.

Turning to the specific question asked by the Committee, Table 2 shows some recommended replacements of EOS sensors with their surface-based (and/or already operational or near-term planned space-based) counterparts, and the reasons for the recommendation.

The list shown in Table 2 is indicative, and not exhaustive.

In conclusion, I find that the EOS program as presently conceived is highly repetitious with past remote sensing programs, appears to aim at "squashing a fly with a sledgehammer", and could be significantly streamlined by extended usage of surface-based sensory systems, in conjunction with judicious substitution of its functious with those of existing and near-term forthcoming earth observation satellites.

TABLE 2

RECOMMENDATIONS FOR REPLACEMENT OF CERTAIN EOS SENSORS WITH SURFACE-BASED SYSTEMS

EOS Sensor	Intended Functions	Replace ?	With What ?	Why ?
MODIS Moderate Resolution Imaging spectrometer	Quantity and type of ocean chlorophyl	Yes	Buoy network/ fluorimetric sensors	Too imprecise
	Ocean temperature	Yes	Buoy network/ thermometric sensors	Too Costly. Also, cannot sense sub-surface temp.
	Cloud cover	Yes	Meteosats	Redundant
	Snow cover	Yes	GOES	Already being done
	Land cover	Yes	LANDSAT 7 and/or forthcoming sats	Resolution of 250-1,000 meters too coarse
Sea Winds	Measure ocean surface winds	Yes	Buoy network/ wind sensor (WOTAN)	Too inaccurate
TRMM Tropical Rainfall Measuring mission[1]	Measure rain-fall	Yes	Raingages on land and on buoys	Too uncertain and inaccurate
	Measure clouds	Yes	Meteosats	Already exists
	Measure radiation	Yes	Meteosats	Already exists
	Measure Lightning	Yes	Vehicle of opportunity	Can be flown on other vehicle

TABLE 2
(continued)

RECOMMENDATIONS FOR REPLACEMENT OF CERTAIN EOS SENSORS WITH SURFACE-BASED SYSTEMS

EOS Sensor	Intended Functions	Replace ?	With What ?	Why ?
EOS Color	Measure production of marine phyto-plankton	Yes	Buoy network/ fluorimetric sensors	Too uncertain and imprecise
	Determine distribution and timing of plytoplankton blooms	Yes	Buoy network/ fluorimetric sensors	Too uncertain and imprecise
MIMR (Multi-frequency Imaging Microwave Radiometer)[2]	Vegetation Status	Yes	Other Earth observation satellites	Too Coarse
	Soil Moisture	Yes	Ground moisture sensors	Too uncertain
	Sea surface temperature, wind, humidity	Yes	Buoy network/ temperature, wind, humidity sensors	Too Coarse

[1] Joint mission with Japan

[2] ESA Instrument

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April 18, 1996

Mr. Brad Hathaway
Associate Director, Defense Management Issues
National Security and International Affairs Division
U.S. General Accounting Office
441 G Street NW
Washington, DC 20548

Dear Mr. Hathaway:

On behalf of the Committee on Science I want to thank you for participating in the *U.S. Global Change Research Programs: Data Collection and Scientific Priorities* hearing held March 6, 1996. I appreciate your time and effort in presenting testimony. Your appearance afforded Committee Members an excellent forum to discuss recommendations for the future of this research program.

Enclosed are additional questions for the hearing record, please provide your response to the Committee by no later than May 2, 1996.

Thanks for your help in making this hearing a success.

Cordially,

Robert S. Walker
Chairman

RSW/cf
Enclosure

Questions Submitted for the Record by the Honorable Robert S. Walker
Chairman, House Committee on Science

Mr. Brad Hathaway
General Accounting Office

1. Based on the FY96 budget request and any available information on out-year spending associated with the FY97 budget are there sufficient resources identified in the NASA budget to fund both the Pathfinder program and an expansion of the funded science community for Mission to Planet Earth?

2. In response to external, internal and Congressional reviews of Mission to Planet Earth, NASA has taken steps to initiate the Earth System Science Pathfinder program to make data collection more flexible than EOS and to make better use of commercial and foreign sources of data. Is NASA effectively funding additional scientific researchers to examine the data from these additional sources, or is NASA simply throwing more data at the same number of principal investigators?

3. NASA has indicated to Congress that the Pathfinder program addresses concerns about scientific inflexibility in the EOS hardware baseline. Presumably, this new program requires more resources. Would it be more cost-effective to restructure the EOS hardware baseline so that EOS itself had the alleged flexibility of the Pathfinder program? What is the added value of the Pathfinder program if the EOS science baseline is supposed to be adequate to answer our key scientific unknowns?

4. Several other agencies fund global change research. What kind of history do these agencies have in funding researchers principally concerned with instruments and data sources funded by NASA?

5. Accepting the fact that UARS and Topex-Poseidon had a science team slightly larger than EOS, but a data rate that is $1/1{,}000^{th}$ of the EOS data rate, as a simple indicator that Mission to Planet Earth is not being fully exploited for the science that it can do, has GAO examined the role that modern information technologies play in improving data handling and analysis of large amounts of data and the role that information technologies play in deriving more useful information from the same number of "bits" as older information technologies?

GAO's Response to Questions Submitted for the Record by the Honorable Robert S. Walker Chairman, House Committee on Science

1. **QUESTION: Based on the FY96 budget request and any available information on out-year spending associated with the FY97 budget are there sufficient resources identified in the NASA budget to fund both the Pathfinder program and an expansion of the funded science community for Mission to Planet Earth?**

ANSWER: NASA has not identified sufficient resources to fund both Earth System Science Pathfinder missions and an expansion of the Earth Observing System (EOS) research community. The administration requested $20 million for Pathfinder for fiscal year 1997, and projected budgets of $30 million in 1998 and $75 million for each year thereafter to 2001. NASA intends to fund this program from future savings generated by lowering costs of other parts of the Mission to Planet Earth program. Similarly, NASA intends to rely on such savings to expand the EOS interdisciplinary research community beyond the 29 teams it currently funds. To date, NASA has not identified the specific sources of these potential future savings, although in general, NASA hopes to lower Mission to Planet Earth program costs through the use of advanced technology and increased collaboration with other agencies, international partners, and the commercial sector.

2. **QUESTION: In response to external, internal and Congressional reviews of Mission to Planet Earth, NASA has taken steps to initiate the Earth System Science Pathfinder program to make data collection more flexible than EOS and to make better use of commercial and foreign sources of data. Is NASA effectively funding additional scientific researchers to examine the data from these additional sources, or is NASA simply throwing more data at the same number of principal investigators?**

ANSWER: Later this year, NASA hopes to solicit proposals for the first and second Pathfinder missions. Until proposals are received and analyzed, the extent to which the Pathfinder program will support additional researchers and make use of alternate sources of data will not be known. In our ongoing work for the Committee, NASA officials told us they expect each Pathfinder mission to support a principal investigator and limited number of guest investigators.

On March 20, 1996, NASA distributed a draft Announcement of Opportunity on the proposed Earth System Science Pathfinder missions for review and comment. The draft Announcement does not specifically define Pathfinder as a way to better use commercial and foreign sources of data or require that such data be used. In the draft Announcement, Pathfinder is broadly described as "focused, limited-duration missions to answer critical questions in Earth System Science not currently addressed within [Mission to Planet Earth]." It states:

> "While it would be most desirable for [Pathfinder] measurements to extend the scope of Earth observations beyond those covered by existing EOS and [Mission to Planet Earth] program elements, it is recognized that new and improved techniques may exist for observing aspects of the global Earth System that are addressed by the baseline EOS 24 measurement sets."

3. **QUESTION: NASA has indicated to Congress that the Pathfinder program addresses concerns about scientific inflexibility in the EOS hardware baseline. Presumably, this new program requires more resources. Would it be more cost-effective to restructure the EOS hardware baseline so that EOS itself had the alleged flexibility of the Pathfinder program? What is the added value of the Pathfinder program if the EOS science baseline is supposed to be adequate to answer our key scientific unknowns?**

ANSWER: As noted previously, NASA says that the primary purpose of the Earth System Science Pathfinder is to make measurements that EOS is not going to make. In our ongoing work for the Committee we have not found that NASA has demonstrated that the potential value of Pathfinder's science would exceed the potential value of additional EOS-related science should savings allocated to Pathfinder instead be allocated to EOS' interdisciplinary science.

4. **QUESTION: Several other agencies fund global change research. What kind of history do these agencies have in funding researchers principally concerned with instruments and data sources funded by NASA?**

ANSWER: Our work for the committee has focused on NASA's Mission to Planet Earth and specifically the EOS part of this Mission. Mission to Planet Earth is NASA's contribution to the governmentwide Global Change Research Program. However, we have not reviewed this larger program. Consequently, we do not currently have information on other agencies' research that may rely, at least in part, on satellite data from NASA-funded instruments. In the course of our work on EOS, NASA officials told us that NASA is the only civilian government agency that solicits research proposals and funds specific space-based earth observation missions.

5. **QUESTION: Accepting the fact that UARS and Topex-Poseidon had a science team slightly larger than EOS, but a data rate that is 1/1,000th of the EOS data rate, as a simple indicator that Mission to Planet Earth is not being fully exploited for the science that it can do, has GAO examined the role that modern information technologies play in improving data handling and analysis of large amounts of data and the role that information technologies play in deriving more useful information from the same number of "bits" as older information technologies?**

ANSWER: We have not recently examined the role of new information technologies to improve data analysis. In our February 25, 1992 report "Earth Observing System: NASA's EOSDIS Development Approach Is Risky," we stated that advanced data base search techniques, new ways of displaying complex interrelationships among data, and efficient access to data stored in archives are all examples of technologies that are critical to the success of the EOS data information system.

The reference to comparative data rates in our statement was in support of our observation that NASA's current EOS basic research community is relatively small compared to two pre-EOS earth science missions (UARS and TOPEX). We also compared the number of science teams associated with these two pre-EOS earth observation satellite missions to their EOS-era counterparts. While we recognize that a data rate comparison is, at best, a rough gauge, taken together, instrument data rates and the number of science teams are indicators of the magnitude of research opportunities afforded by EOS-era satellites and two predecessor missions.

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*Ranking Democratic Member

April 18, 1996

Dr. Edward Frieman
Director, Scripps Institution of Oceanography
9500 Gilman Drive
La Jolla, CA 92093-0210

Dear Dr. Frieman:

On behalf of the Committee on Science I want to thank you for participating in the *U.S. Global Change Research Programs: Data Collection and Scientific Priorities* hearing held March 6, 1996. I appreciate your time and effort in presenting testimony. Your appearance afforded Committee Members an excellent forum to discuss recommendations for the future of this research program.

Enclosed are additional questions for the hearing record, please provide your response to the Committee by no later than May 2, 1996.

Thanks for your help in making this hearing a success.

Cordially,

Robert S. Walker
Chairman

RSW/cf
Enclosure

Questions Submitted for the Record by the Honorable Robert S. Walker Chairman, House Committee on Science

Dr. Edward Frieman
Scripps Institution of Oceanography

1. The NRC study of Mission to Planet Earth makes no reference to costs or the need to balance Mission to Planet Earth against other NASA and scientific programs. Did the Committee on Global Change Research consider EOS costs or NASA's projected budget?

2. The President's out-year budget for NASA projects Mission to Planet Earth costs rising to nearly $1.6 billion in fiscal year 2000, more than we spend on space science, about twice as much as NASA spends on aeronautics, and about two and a half times as much as NASA spends on life and microgravity research. As Members of Congress, we have the responsibility to determine how we trade one program off against another, since the American taxpayer cannot be treated as a bottomless money-pit, so the Committee would appreciate your advice as we work to do this. Do you think we should spend more on building hardware for climate change research than we do on studying human physiology or new aeronautical technologies?

3. The NRC study discusses non-EOS data sources for global change research as things to be added to EOS. Do you anticipate that adding these things to EOS will increase or decrease Mission to Planet Earth's costs between now and the year 2002, which is our target date for balancing the budget?

Did the Committee study how well these non-EOS data sources might provide data that addresses our baseline scientific questions and possibly lower our costs by reducing the need for particular EOS sensors?

4. The report contains no cost-benefit analysis of EOS sensors and platforms versus other data collection methods when it comes to meeting our scientific data requirements. Did the Committee conduct a cost-benefit analysis of EOS sensors and platforms to determine how well they met our science requirements as opposed to other systems, and if so, how was that analysis conducted?

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EDWARD A. FRIEMAN
DIRECTOR
SCRIPPS INSTITUTION OF OCEANOGRAPHY

May 2, 1996

The Honorable Robert S. Walker
Chairman, House Science Committee
2320 Rayburn House Office Building
Washington, DC 20515-6301

via facsimile (202) 226-0113

Dear Mr. Chairman,

Thank you again for inviting me to participate in the *U.S. Global Change Research Programs: Data Collection and Scientific Priorities* hearing held March 6. This is in response to the questions you submitted for the record (see attached).

1. The NRC group which carried out the study of Mission to Planet Earth you requested, was well aware of the general S&T downward budget pressures and that those pressures affected NASA as well. In that regard, the study focused on the combined goals of reducing the costs of the EOS/EOSDIS component of MTPE while preserving or bettering the critical science.

While detailed costing algorithms were not examined, we informally estimated that the totality of our recommendations could save hundreds of millions of dollars. Our current information from NASA indicates that the EOS/EOSDIS program restructuring along the lines recommended by the study might well achieve savings of that magnitude.

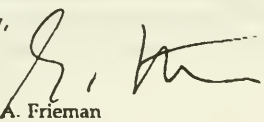
2. Issues of priority between competing components of the budget raise complex concerns which were not addressed in our study. I believe however, that the issues you raise deserve to be addressed in a broader context. There is broad agreement on the goals we have adopted as a nation: to be economically competitive, to assure the health and well being of our citizens, to provide a strong defense for ourselves and our allies, to leave the planet in sound shape for succeeding generations and simultaneously to push back the frontiers of knowledge. The US Science and

Technology research agenda needs to be examined with the view of setting priorities to achieve these national goals. Such a detailed analysis could provide the framework for addressing the important questions you raise.

3. The NRC study focused on two major issues: the overall USGCRP, and its largest component NASA's Mission to Planet Earth. EOS is, of course, the major part of NASA/MTPE. The non-EOS data sources discussed were, for the most part, components of the other agencies programs in the overall USGCRP. We urged joint planning between the space and non-space segments to achieve more and better science. This incurs no increased cost but simply demands a higher level of cooperation and planning. Both sources of data are needed to make scientific progress.

4. We interpreted your charge to the NRC as wanting a critical analysis of EOS/ EOSDIS and the USGCRP including new opportunities offered by convergence opportunities between government agencies as well as use of commercially available technology and services. Unfortunately, the DOD/NOAA/NASA convergence program has just been delayed for some time. Various commercial opportunities were examined and appear very promising in the longer term. While no detailed cost-benefit analyses were carried out, it appeared clear that costs would rise if delays were instituted to allow the newer technologies and offerings to be utilized.

Sincerely,



Edward A. Frieman

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Questions Submitted for the Record by the Honorable Robert S. Walker Chairman, House Committee on Science

Dr. Edward Frieman
Scripps Institution of Oceanography

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April 18, 1996

Dr. Arno Ledebuhr
Lawrence Livermore National Laboratory
PO Box 808
7000 East Avenue, Mail Stop L-47
Livermore, CA 94550

Dear Dr. Ledebuhr:

On behalf of the Committee on Science I want to thank you for participating in the *U.S. Global Change Research Programs: Data Collection and Scientific Priorities* hearing held March 6, 1996. I appreciate your time and effort in presenting testimony. Your appearance afforded Committee Members an excellent forum to discuss recommendations for the future of this research program.

Enclosed are additional questions for the hearing record, please provide your response to the Committee by no later than May 2, 1996.

Thanks for your help in making this hearing a success.

Cordially,

Robert S. Walker
Chairman

RSW/cf
Enclosure

Questions Submitted for the Record by the Honorable Robert S. Walker Chairman, House Committee on Science

Dr. Arno Ledebuhr
Lawrence Livermore National Laboratory

1. According to your testimony in 1991, the Department of Energy proposed using miniaturized spacecraft technology developed at great expense during the Cold War to reduce the costs and improve the robustness of Mission to Planet Earth by flying EOS-class instruments on a distributed remote sensing constellation of ten satellites in 1995 at a cost of only $370 million, which compares very favorably with the $1.2 billion dollar cost of developing just the first EOS-PM spacecraft. NASA rejected the proposal, and we know from the Federal Laboratory Review that Mission to Planet Earth remains outside NASA's faster, cheaper, better culture and suffers from a "not invented here" syndrome. Could you elaborate on the reasons that NASA gave for not pursuing this concept in 1991?

2. The White House has directed that we capitalize on our Cold War technology investments for dual-use applications in the commercial and civil science sectors. I think that is a sentiment we can all wholeheartedly support and would like you to suggest any steps that we might take to leverage DoE technologies and capabilities to help us reduce the cost of Mission to Planet Earth while improving our ability to do science instead of warehouse data.

3. NASA has indicated that it will use the New Millennium program to develop new technologies to lower the cost of collecting data from space and that the New Millennium program will draw on the skills and capabilities of various government agencies and the private sector. Could you comment on Energy Department technologies and programs that would be candidates for this aspect of the New Millennium program?

Lawrence Livermore National Laboratory

May 1, 1996

MAY 0 2 1996

Mr. Robert S. Walker
Chairman
U. S. House of Representatives
Committee on Science
Suite 2320 Rayburn House Office Building
Washington, D.C. 20515-6301

Dear Mr. Walker:

Enclosed is my response to additional questions for the hearing record. If you should need further assistance call me at (510) 423-1184 or you can fax me on (510) 423-1243.

Cordially,

Arno

Arno Ledebuhr
Lawrence Livermore National Laboratory
Livermore, CA. 94550

Enclosure (1) Disk

Answers to Questions Submitted for the Record by the Honorable Robert S. Walker Chairman, House Committee on Science

Dr. Arno G. Ledebuhr
Lawrence Livermore National Laboratory
April 30, 1996

Question:
1. According to your testimony in 1991, the Department of Energy proposed using miniaturized spacecraft technology developed at great expense during the Cold War to reduce the costs and improve the robustness of Mission to Planet Earth by flying EOS-class instruments on a distributed remote sensing constellation of ten satellites in 1995 at a cost of only $370 million, which compares very favorably with the $1.2 billion dollar cost of developing just the first EOS-PM spacecraft. NASA rejected the proposal, and we know from the Federal Laboratory Review that Mission to planet Earth remains outside NASA's faster, cheaper, better culture and suffers from a "not invented here" syndrome. Could you elaborate on the reasons that NASA gave for not pursuing this concept in 1991?

Answer:
1. To my knowledge the 1991 Pathfinder program concept was only presented at the EOS Engineering Review Advisory Committee and was <u>not</u> formally proposed to NASA. Furthermore, it was presented by Lawrence Livermore National Laboratory as an outgrowth of work being done for the Department of Defense and was not specifically endorsed by either the Department of Defense or the Department of Energy. Lawrence Livermore's objective was to suggest a different pathway towards achieving NASA's objectives given experience the Laboratory had acquired at that time with light weight and advanced component technologies. The Livermore concept was contained in the committee record and was discussed by the NASA attendees present at the committee meeting. As far as I am aware, no formal calls occurred for proposals of this type and no formal submittal of this program proposal was made to NASA. However, interest in the capabilities of these technologies were expressed by NASA attendees and during this time frame, at least one Technical Interchange Meeting occurred at LLNL in which all of our various technology developments were presented to NASA representatives. No joint programs resulted from these discussions.

Arno G. Ledebuhr
Lawrence Livermore National Laboratory

Question:
2. The White house has directed that we capitalize on our Cold War technology investments for dual use applications in the commercial and civil science sectors. I think that is a sentiment we can all wholeheartedly support and would like you to suggest any steps that we might take to leverage DoE technologies and capabilities to help us reduce the cost of Mission to Planet Earth while improving our ability to do science instead of warehouse data.

Answer:
2. First I would like to again clarify that the remote sensing technologies that were discussed in my testimony, were developed under Department of Defense sponsorship and not Department of Energy sponsorship. With this in mind, I would like to answer the first part of the question, which is asking for suggestions on "any steps that we might take to leverage DoE technologies and capabilities to help us reduce the cost of Mission to Planet Earth". I believe that it is clear based on the demonstration of the remote sensing capabilities of the Clementine spacecraft, our current Clementine II program efforts, and work undertaken at TRW on the Lewis spacecraft for NASA, as well as other commercial ventures, that the technology and expertise exists to rapidly field a pathfinder spacecraft similar to that described in the original 1991 program plan.

Lawrence Livermore National Laboratory has continued to develop pace setting lightweight, high performing sensors for use on DoE and DoD missions. These instruments can be constructed, characterized, and calibrated to standards sufficient to generate the necessary level of accuracy in scientific measurements. Furthermore, LLNL has demonstrated the capability to develop analytic models which provide the basis for understanding the measurements made. Finally, industry is rapidly demonstrating the capability to produce light weight, low cost and high performing spacecraft capable of carrying Livermore type sensors. I would therefore suggest that if Congress were to direct the undertaking of a constellation of Clementine-like prototype spacecraft, optimized to carryout EOS remote sensing tasks, the nation could have an alternative and independent pathfinder to NASA's EOS, that is committed to the "faster, cheaper, better" culture. This would leverage the ongoing program efforts, technology developments and capabilities which should lead to a reduction in the overall cost of the Mission to Planet Earth program.

The second part of the question addresses a desire of "improving our ability to do science instead of warehouse data". I can not speak to how NASA handles its science data, but the key to success is to focus on the management of the acquisition, distribution, and analysis of data and the compilation of findings. The DoE laboratories, including LLNL, have several areas of scientific competence that could support the Mission to Planet Earth program. Specifically the Department of Energy has been funding an Atmospheric Radiation Measurements program that supports a robust science program that includes data collections from multiple platforms and a complex modeling effort. LLNL has developed state-of-the-art instrumentation, global climate modeling codes, advanced data visualization approaches and data fusion techniques that could significantly leverage NASA's efforts in this area. We are also developing techniques to handle hyperspectral data cubes to provide the capability for gaseous effluent identification in near realtime.

In summary, the capability exists at national laboratories like Livermore to bring Cold War technology investments and scientific heritage to support applications in the commercial and civil science sectors. All that is required are funded mandates.

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Arno G. Ledebuhr
Lawrence Livermore National Laboratory

Question:
3. NASA has indicated that it will use the New Millennium program to develop new technologies to lower the cost of collecting data from space and that the New Millennium program will draw on the skills and capabilities of various government agencies and the private sector. Could you comment on Energy Department technologies and programs that would be candidates for this aspect of the New Millennium program?

Answer:
3. Lawrence Livermore National Laboratory has demonstrated a variety of remote sensing technologies that could be further enhanced and extended under NASA's New Millennium program. Two examples of these technologies are the stand-alone imaging package for the COMET/METEOR spacecraft and a new hyperspectral imaging sensor technology developed at LLNL.

The COMET/METEOR payload incorporated enhanced versions of two of the Clementine sensors. One was an improved imaging camera which would have provided 5 meter ground imagery from a 400 km orbit and a second was a camera which incorporated state-of-the-art wedge filter technology to construct a compact imaging spectrometer from an existing Clementine design. This combined system with a stand-alone control processor weighed only 8 kg and would have provided both high spatial and spectral resolution capability in a single package. Unfortunately, the COMET/METEOR package was lost with the failure of the Conestoga launch last Fall. However, this is still a very enabling remote sensing technology for micro spacecraft applications and its performance could be extended with further development funding.

Recent LLNL developments in compact imaging hyperspectral instrumentation have very high spectral resolution performance in the mid- to long-wave infrared portions of the spectrum. These developments have demonstrated a new remote sensing capability that is under investigation by DoE to determine its utility for the assessment of proliferant activities. This capability would have broad application in a number of NASA mission areas and as such would make an excellent candidate for the New Millennium program.

These are just two examples of applicable remote sensing technologies that exist at LLNL. In addition, there are many other remote sensing technologies within the DoE weapons laboratory complex, that in this context, may be of interest to NASA.

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*Ranking Democratic Member

April 18, 1996

Dr. Robert Balling
Office of Climatology
Arizona State University
Tempe, AZ 85287

Dear Dr. Balling:

On behalf of the Committee on Science I want to thank you for participating in the *U.S. Global Change Research Programs: Data Collection and Scientific Priorities* hearing held March 6, 1996. I appreciate your time and effort in presenting testimony. Your appearance afforded Committee Members an excellent forum to discuss recommendations for the future of this research program.

Enclosed are additional questions for the hearing record, please provide your response to the Committee by no later than May 2, 1996.

Thanks for your help in making this hearing a success.

Cordially,

Robert S. Walker
Chairman

RSW/cf
Enclosure

Questions Submitted for the Record by the Honorable Robert S. Walker Chairman, House Committee on Science

Dr. Robert Balling
Arizona State University

1. Given the strengths and weaknesses of computer models of the climate, what do you think their proper role in understanding the climate is?

2. In funding climate researchers, the government faces a wide variety of competing interests. How do you recommend we prioritize those interests among data collection, modeling, and theoretical development, with the understanding that some activities inherently cost more than others regardless of their relative prioritization.

ASU
ARIZONA STATE UNIVERSITY

Office of Climatology
Community Services Center
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April 24, 1996

Mr. Robert S. Walker
U.S. House of Representatives
Committee on Science
Suite 2320 Rayburn House Office Building
Washington, D.C. 20515-6301

Dear Mr. Walker:

Thank you for the continued interest in the global warming debate. My answers to your two questions are given below:

(1) The large, three-dimensional climate models of the world are fantastic achievements in atmospheric physics, computer science, and applied mathematics. The models do a credible job replicating the basic features of the climate system, particularly if one is concerned with atmospheric circulation. The construction and use of the models have greatly increased our understanding of the climate system, and even without any greenhouse debate, I believe the models have been well worth the expenditure in financial and human resources.

The shortcomings of the models with respect to predicting future climates have been discussed in detail by other panelists. Representations of cloud and precipitation processes, air-sea interactions, biological responses, and sea-ice variations are still crude in the models. Given these problems with the models, it is imperative for us to carefully evaluate each model prediction, and in many cases, this involves comparing model outputs to observed variations and trends in climate. In many ways, herein lies the basis for the "heated debate."

I do not consider myself a climate modeler, but I do follow the relevant literature as relates to the global warming issue. I believe we have gained enormously from the development of these models, but I am not prepared to believe fully in their predictions for the future.

(2) The highest priority should go toward the development of the theoretical models of climate. The second priority should be in data collection and analysis, with particular emphasis on satellite-based measurements. As it turns out, these two high priorities are highly interrelated, and highly important if we are to get any glimpse of our climatic future. In my view, the so-called impact studies should be given the lowest priority for government funding.

Sincerely,

Dr. Robert Balling
Director, Office of Climatology

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*Ranking Democratic Member

April 18, 1996

Dr. Robert Davis
Department of Environmental Sciences
Clark Hall University of Virginia
Charlottesville, VA 22903

Dear Dr. Davis:

On behalf of the Committee on Science I want to thank you for participating in the *U.S. Global Change Research Programs: Data Collection and Scientific Priorities* hearing held March 6, 1996. I appreciate your time and effort in presenting testimony. Your appearance afforded Committee Members an excellent forum to discuss recommendations for the future of this research program.

Enclosed are additional questions for the hearing record, please provide your response to the Committee by no later than May 2, 1996.

Thanks for your help in making this hearing a success.

Cordially,

Robert S. Walker
Chairman

RSW/cf
Enclosure

Questions Submitted for the Record by the Honorable Robert S. Walker Chairman, House Committee on Science

Dr. Robert Davis - University of Virginia

1. If I understand your testimony correctly, than the big snowstorms that we've experienced this Winter cannot be shown to have been caused by global warming and are the result of a separate phenomenon. Does that mean that Newsweek magazine got its front page story wrong when it blamed global warming for the snowstorms?

2. How prevalent is the process of using climate models to validate themselves?

3. Understanding that some activities inherently cost more than others, how would you prioritize the Federal Government's funding of climate change research among data collection, modeling, theoretical development, and analysis of existing databases to improve our ability to do the most productive science?

DEPARTMENT OF ENVIRONMENTAL SCIENCES
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April 30, 1996

Robert S. Walker, Chairman
Committee on Science
U.S. House of Representatives
Suite 2320 Rayburn House Office Building
Washington, DC 20515-6301

MAY 0 2 1996

Dear Mr. Walker:

Enclosed are my responses to your questions stemming from my testimony before your Committee on March 6, 1996. Thank you for the opportunity and privilege of testifying before your committee, and best wishes to you and your family as you resume your post-Washington life.

Regards,

Robert E. Davis

Robert E. Davis
Associate Professor

enclosure

QUESTIONS SUBMITTED BY ROBERT S. WALKER, Chairman, Committee on Science, U.S. House or Representatives.

1) If I understand your testimony correctly, the big snowstorms that we've experienced this winter cannot be shown to have been caused by global warming and are the result of a separate phenomenon. Does that mean that Newsweek magazine got its front page story wrong when it blamed global warming for the snowstorms.

Yes, *Newsweek*, and the experts they consulted on this issue, got the story completely wrong. Mid-Atlantic snowstorms like the ones so prevalent this past winter, are rarely moisture-limited. Any future enhancement of the hydrologic cycle will have little or no effect on mid-Atlantic snowfall totals.

2) How prevalent is the process of using climate models to validate themselves?

This process is becoming more prevalent in recent years. Existing historical data archives are frequently being dismissed as biased or temporally or spatially unrepresentative. To allow comparisons between observations and model output (which are on regular grids), observations are interpolated from irregular station locations to regular grids. This interpolation generates error.

It is obviously easier to compare model output to observations on the same grid networks. But the ease of this type of comparison makes it neither correct nor defensible.

3) Understanding that some activities inherently cost more than others, how would you prioritize the Federal Government's funding of climate change research among data collection, modeling, theoretical development, and analysis of existing databases to improve our ability to do the most productive science?

Thank you for asking my opinion on this very important topic. The most important consideration, from a climatological and global change standpoint, is to maintain the integrity of the data observations collected over time. This indicates that changes in observing networks, instruments, siting, etc. must be made with the long-term time series in mind. If we cannot preserve the historical data records, we will soon have no data for model validation (see my response to the above question.) Thus, I would prioritize these areas as follows:

1) data collection (top priority)
2) data analysis
3) theoretical development
4) modeling.

The Federal Government must be keenly aware of the return on its (the taxpayer's) investment. There can be little debate on the return realized from item #1--can the same be said for #4?

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*Ranking Democratic Member

April 3, 1996

Dr. Patrick Michaels
Department of Environmental Sciences
University of Virginia, Clark Hall
Charlottesville, VA 22903

Dear Dr. Michaels:

I want to extend my appreciation to you for your recent testimony before the Committee on Science regarding Global Change and the Earth Observing System.

Enclosed are some additional questions intended to clarify certain issues. I request that you provide written responses to these questions by May 1. Your responses will be made a part of the hearing record. If you have any questions, please contact Dr. William Smith of my staff at 202/225-4439.

Once again, thank you for your participation in this important hearing.

Sincerely,

George E. Brown Jr.

GEORGE E. BROWN, JR.
Ranking Democratic Member

Enclosure

QUESTIONS FOR DR. MICHAELS

1. In your testimony, you suggest that recent evidence has changed the scenario from the "dangerous" to the "moderate" scenario. The IPCC, however, has chosen not to define "dangerous" or "moderate," maintaining that such a determination is more appropriate for politicians than for scientists.
    - Do you agree with this contention of the IPCC?
    - What was the basis for this statement in your testimony, i.e. your personal opinion, a formal determination or judgment by another body, etc.,

2. The first figure that you showed in your presentation you said compared the pre-Rio model simulation for temperature rise due to the rise in CO2 concentration over the 20th century to the history of the Northern Hemisphere temperature.
    - Please explain your reasoning for comparing a CO2 only simulation to the observed record when the IPCC report clearly says that other factors would have been affecting the temperature record.
    - Please explain why you chose to compare the model simulation to the Northern Hemisphere record when the model simulations are for changes in global temperature.

3. In your presentation of the MSU data record, you, unlike Dr. Christy, chose not to adjust the MSU data to account for the changes in temperature that are almost certainly caused by the occurrence of ENSO episodes and volcanic eruptions.
    - Do you not agree that, when trying to derive trends from a relatively short record care must be taken to prevent being misled by infrequent events?
    - Do you disagree with Dr. Christy's analysis that suggests, when the adjustments are made, the temperature trend in the MSU data is positive?

4. In your comparison of MSU and surface temperature data, you do not account for a number of articles and factors suggesting that the two quantities are different. Articles by Dr. Trenberth, for example, show spatial correlations of the two variables that are quite low in some regions because of inversions, because the tropospheric temperature over high-latitude oceans is much more responsive than is the sea surface temperature below, and vice versa over the land (especially where inversions are created). In addition, the MSU temperature is sampled twice daily whereas the land surface temperature is the average

of the maximum and minimum (perhaps giving a different result than the MSU if only nighttime warming is occurring.

- What is the basis of your argument that the surface temperature (as it is calculated) and the tropospheric temperature should be giving exactly the same result?

5. You comment that the MSU record is well correlated with the radiosonde record. The combined record thus gives a longer indication of the trend in tropospheric temperature.
   - Why is it that you do not show this combined record, which better approaches the 30 year length of record that climatologists favor?
   - Do you agree that this longer record shows a temperature increase over the period of record, even before adjusting for the various other natural forcings (volcanoes, ENSOs, solar)?

6. In your presentations, you suggest that because there are no sulfate aerosols in the Southern Hemisphere, there should be no effect there. You make similar arguments with regard to changes in ozone concentration and to where temperature changes should occur in the Northern Hemisphere due to the presence of aerosols. Yet, major advances in weather forecasting occurred when hemispheric models were made global, and most meteorologists believe that ice sheets in the northern hemisphere affect the southern hemisphere and so on.
   - Do you not agree that the atmosphere is interconnected and that perturbing it in one place will affect it in others?
   - Do you disagree with Dr. Lindzen who argues that the regional distribution of energy is a critical determinant in changing the global climate (note that he argues that changing orbital elements led to radiation changes in particular regions that affected the global climate)?
   - Do you disagree with model results that show that sulfate aerosols have effects on temperature well beyond regions where they are concentrated?

7. In your oral testimony you seem to imply that there is only one study concerning the role of sulfates as an explanation for the difference between observations and the results of CO2 only simulations. The IPCC report describes quite a number of such calculations and subsequent ones are underway by many groups, and the issue is itself raised in the IPCC 1992 and even the IPCC 1990 reports. The number of articles in the literature seems much beyond the one that you mention. Please comment.

8. You seem to dismiss the findings of Dr. Karl on extreme events when he seems to be doing just the sort of empirical data analysis that you encourage. That is, Dr. Karl found that changes were occurring and that this was consistent with predictions of climate change to date.
    - Are you saying such an increase is not occurring (and if so, on what analytical basis)?
    - Finally, what is the scientific basis for your statement that "almost all" of the rainfall events with precipitation over two inches are beneficial?

9. You have strongly implied that no human-induced climate change could have occurred before 1950 (or even until later if your statement about 1930 to 1950 being "long before the greenhouse effect could have done this" is correct).
    - What is your basis for saying this? The CO2 and CH4 concentrations were surely rising prior to 1950 (due to changes in land cover and fossil fuel burning) and would have had a radiative influence. While the warming effect may have been suppressed in mid-century by the rising number of tall stacks emitting sulfur dioxide, how can you say that no change could have occurred prior to 1950?

10. In your discussion of the IPCC results, you say that the IPCC in 1990 projected a temperature change of 1 degree Celsius in 2025, or about 0.3 C per decade. This estimate was made for a particular scenario of greenhouse gas concentrations only and a particular assumption about model sensitivity, and that aerosols and other factors were recognized as likely to affect this estimate.
    - Do you agree that the IPCC actually predicted a range of possible temperature changes for 2025 based on different sensitivities and scenarios?
    - Do you agree that some of the decrease in the estimate since that time been a result of controls taken on CFC emissions that were clearly different than the Business-as-Usual scenario so that your claim of being right actually suggest magical insight about CFC controls?
    - Do you agree that some of the decrease in the estimate since that time been as a result of new attempts to quantify the aerosol effect that was mentioned as needing to be treated in the 1990 and 1992 reports?

11. A press release on February 15, 1996 by Western Fuels Association, Inc. indicates that they will be funding you and others (including two others on this panel) to put out a report this April that will be used as a

tool "to reveal this ongoing fraud [of apocalyptic global warming]." Some assert that this press release gives the impression that the results of your studies are preordained by your sponsor, and that there is a clear agenda to your work. You indicated in your answers to some of the questions that having an industry sponsor has no effect on your research.

- How can you reconcile this with the statement in the Western Fuels press release?
- You also argue that peer review is the cleanser to ensure elimination of any bias; will you be circulating this report for peer review (for example, to those who prepared the IPCC report and those being accused of fraud)?
- Will you be accommodating reviewer comments (or at least providing a specific response to each comment)?
- If you do seek review of this report, will you please provide the Committee a list of the names and affiliations of all of the reviewers and a copy of all the reviewer comments and your response to each?

12. In your response to a question, you indicated that Dr. Mitchell's results were 160 to 360 percent in error.

- Could you please explain how you made this calculation, and indicate why a difference between a greenhouse only model result and the observations should apparently be the basis for calculating an "error?" The transient model simulations in the 1992 report were for the arbitrary case of a 1% per year increase in CO2 and so it is not clear how it is relevant to compare them to observations or to the current transient simulation with CO2 only.

13. You mention that you submitted a paper to Science magazine in 1993 and that it was not published. Could you provide a copy of the paper and the review of the paper for the record? On what basis do you argue that this hearing provides the first discussion of the difference between models and observations that you cited at this hearing?

14. Your results and interpretations of them suggest that finding that the warming is less than in earlier models may reduce the urgency for taking action.

- If the reduced estimate of current warming is due to aerosols and the underlying warming potential of greenhouse gases is found to be correct as predicted by earlier models, which is what the IPCC report seems to conclude, do you still believe that action can be deferred?

- Please explain the basis for making any statement about this, your experience in the area, and whether you are making this statement as a scientist or a citizen?

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MEMORANDUM

April 29, 1996

TO: The Hon. George E. Brown, Jr., Committee on Science, U.S. House of Representatives.

FROM: Patrick J. Michaels, Research Professor

RE: Questions on Testimony

Following are the answers to the questions tendered on my Testimony of March 6, 1996, before the House Science Committee.

1. No. IPCC should define its terms, using Webster's definitions. In fact, the problem with the Framework Convention is that it's nondefinition of "dangerous" may in fact be "dangerous" to individual nations, including the United States.

My statement about "moderate" vs. "dangerous" is based upon:

1) The now-well-documented failure of the transient coupled ocean-atmosphere models that based the Framework Convention. Mitchell et al. (1995a) argue that the range of error in nonsulfate adjusted models of this type is currently in the range of 1.3°C-2.3°,

2) The sulfate-adjusted model of Mitchell et al. (1995b), which has 1.3°C of warming remaining to the year 2100,

3) The calculation of Wigley et al. (1996), independent of (2), which also indicates 1.3° of warming remaining to the year 2100,

4) Upwelling-diffusion calculations in IPCC (1990), which give 1.3° of warming for CO_2 doubling based upon the empirical history of climate,

5) Ratio-based calculations between coupled (nonsulfate) ocean-atmosphere models and observed climate also lead to a range of 1.0°-1.5°C for doubling, as I have noted in earlier testimony (See November 16, before the Subcommittee on the Environment). This can be calculated from three independent sources of climate data--satellites, surface thermometers, and radiosondes.

6) Recent calculations by the Goddard Institute for Space Science (Tegen, et al., 1996), headed by Dr. James Hansen (whose 1988 testimony on "cause and effect" and "certainty" is of historical proportion), demonstrating that the net human forcing on the climate is, to date, *negative*. If this is true, it indicates how inaccurate IPCC's "consensus of scientists" was and is.

2. I was using *effective* CO_2, which combines all of the other gases. The Rio suite of models did not include sulfates, nor an estimate of the magnitude of error that, at the time, existed. People need to know what it was, don't they, given the serious nature of the Framework Convention? Or is it a piece of information so inflammatory that it could undermine the Treaty, and therefore it should be suppressed? Why is everyone so scared about this?

The Northern Hemisphere temperature record is more reliable, because of coverage and the fact that Antarctic stations are not included in the Southern Hemisphere record until 1957.

3. ENSO is an internal oscillation in the climate system and should never be removed from a record of historical nature! Christy's MSU adjustments are clearly unrealistic for Mt. Pinatubo at this time. His current adjustment indicates an effect equal to nearly the *maximum* from El Chichon, and yet the stratosphere is virtually free of Pinatubo aerosol. Thus one must question the entire paramterization of the "adjustment".

With regard to length of record, the satellite history is now in its 18th year. The free atmosphere temperature behavior, according to the models, should be relatively smooth when compared to the surface, and the warming trend should be obvious.

4. The global correlation between the surface and the MSU temperatures is undeniably very high and very significant. However, one (the surface record) has a warming trend that is not in the MSU data. (The correlations are high because the peaks and valleys line up.) The hemispheric correlations are also very high, for the same reason. I was comparing hemispheric, surface and MSU temperatures. We were talking about global (and hemispheric) warming at the hearing, weren't we?

5. I testified on November 16 (before the Subcommittee on the Environment) that the Oort et al. upper air record (from the DOE summaries) shows a significant warming in the 850-300mb layer, but that all of the power in this trend was generated between 1976 and 1977, or twenty years ago. There is no trend in 1964 (when the record begins) to 1976, and none

in 1977-94. This is a result that hardly agrees with any modelling study!

6. The correspondence between the hemispheres is in largest part the El Nino signal, and the correspondence degrades massively between the two high latitude regions. The statement about ice sheet correlations is true only in the grossest sense; the scientific literature has been very inconsistent about Antarctic/North Polar teleconnections.

The model you refer to is by Taylor and Penner. As Joyce Penner noted at the Global Change Research Seminar held in the Rayburn Building on April 25, it has underestimated the known positive greenhouse forcing (2.5 w/m^2) by 40%. The sulfate effect (modelled at around -0.6 w/m^2) is smaller than the known error in the positive greenhouse forcing. It is unwise to speculate about what is true, and what is not, based upon a model that is clearly in error in its basic assumptions. Further, if one chooses to tout this result as "correct" in temperature, it therefore must have been right for the wrong reasons.

Orbital forcing is in fact a global forcing that exerts regional effects. Of course global forcings are expressed differentially in different regions! But that does not mean there is a *strong* connection between the Northern and Southern hemisphere that is mitigated locally (except, as noted above, by El Nino).

7. I tend to emphasize the Mitchell et al. (1995b) study because it is consistent with the global average temperature observations (it does fail badly at high latitudes). The aforementioned Taylor and Penner model, which looks good at first glance, suffers from the greenhouse forcing problem noted above. IPCC 1990 and 1992, despite (mainly in 1992) some words about sulfates, both claimed that the nonsulfate models were in general agreement with the climate. By 1995, IPCC finally acknowledged the well known failure of those models. Wigley et al. (1996) gives results very consistent with Mitchell (1995b). Finally Tegen et al. (1996) completely disavow the old saw that the old models were consistent with observations by calculating a net aerosol + greenhouse forcing to date that is *negative*.

8. I did not dismiss Tom Karl! I said that his largest change in two inch rain ("extreme" is not a correct description for this) was before the largest changes in forcing, and that the change in frequency is so small (one more day in 730 days) that it surely supports a "moderate" rather than "dangerous" interpretation of anthropogenerated change.

70% of all 24 hour rainfall events that are greater than 2.0 inches are less than 3.0 inches; that's an easy calculation from Karl's data, and a result generally known to climatologists. Karl's study pertains only to summer rain in the conterminous U.S. That region is generally in moisture deficit during the summer, and it is doubtful that most rainstorms of 2-3 inches are viewed with dismay!

9. Emissions of CO_2 rose dramatically after 1950, compared to previous decades. Obviously there were small changes in sulfates prior to 1950...but to argue against my

assertion is to argue against the IPCC, who stated in 1990 that "The rather rapid rises in global temperature around 1920-1940 are very likely to have had a mainly natural origin". Has the "consensus of scientists" changed? Or is it the opinion of the scientist who wrote the question that has changed??

10. Correct. It is based upon emission rates that have by and large been maintained for the last six years, which corresponds to the BAU scenario (with a small adjustment for the Montreal Protocol). But we are much closer to BAU than we are to Scenario B, the next lower one, which gives a rise of 67% of this value. Obviously the IPCC forecast from 1990 is failing.

Anyone who seriously believes we will induce large and expensive emission reductions ought to read today's newspaper, where The President has proposed repeal of the $.043/gal. gasoline tax, which was originally the BTU tax, which was originally the carbon tax to fight global warming! So we stay much nearer to BAU than scenario B, don't we? And therefore it is demonstrable that too much warming has been predicted.

IPCC (1992) does lower its estimate because, it states, of both CFCs and new population estimates. I believe, as I have testified, that it was also well known (but not stated by IPCC) that the transient models were far too warm *at that time* and that was an additional, unstated, factor that was involved in the reduction of estimated warming. If it was not known at that time, then the simplest test of the models had not been performed, a terrible indication of a lack of scientific competence that I refuse to believe can possibly be real. *At what time in the Framework Convention process did IPCC know that the overprediction of current warming was approximately 300%?* My understanding is that investigative journalists are actively pursuing this question.

11. I can hardly control what someone says in a press release. If you mean to imply that my results are colored by my funding, consider that now 80% of my research funding is from public, tax-supported, sources, and 20% is from industry. If you mean to imply my results are colored by my funding, please consider the large amount of industry funding that supports research in the biomedical sciences at University of Virginia. Are you saying that the faculty here, in such a highly regarded institution, consists of a large number of liars?

I have never used the word "fraud" with regard to global warming predictions. However, with regard to peer review, all of the sources in the "State of the Climate" report are in fact peer-reviewed (unlike IPCC drafts), and I include the list as an appendix.

12. The transient coupled ocean-atmosphere models base the 1992 IPCC volume created for the Rio Earth Summit. They are in error by the amount stated. I have performed calculations where the 1% increase is spread out (becomes less per year) to more realistically mimic what happened. They were published in the refereed literature (*Bulletin of the American Meteorological Society)* in 1993. This allows the models more time to

warm up than does reality and should reduce model error. It still comes out as about 1 globally.

13. I have provided the reviews in the record in my November 16, 1996, testimony to the Subcommittee on the Environment.

14. Yes. So does Wigley et al. (1996). Apparently so does President Clinton, judging from his gasoline tax proposal.

I would argue that it *should* be deferred because, as a scientist, it is obvious to me that there is a certain amount and rate of climate change that the earth's biosphere regularly has seen in geological time, and 1.3°/century (the most likely amount: see Question 1) is certainly within this range.

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APPENDIX: Reference list from the *State of the Climate-1996*, published by Western Fuels Association. All citations are from published papers in the refereed literature, an improvement over drafts of IPCC documents sent to reviewers.

"Global warming will become a presidential campaign issue. It is a statistical fact that during every summer and fall there is usually a portion of the United States that experiences considerable drought. We will hear speeches, given there, about how it was caused by global warming. And the rhetoric may really heat up with the publication of *Our Stolen Future*, a book blaming a highly speculative decline in sperm counts on agriculture and industry (who else?). At the least, global warming will be predicted to exacerbate the problem because it requires the use of more agricultural pesticides. At worst, it will be blamed directly as a cause. "Skeptics" will argue that there are an awful lot of children in the tropics and not very many in Antarctica.

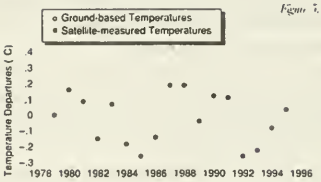

Figure 5.

Figure 5. The satellite temperature record (solid circles), and the ground-based record (open circles), history from the U.S. Department of Energy. Values expressed as departure from 1979, which is the start of the satellite record.

Figure 6.

Figure 6. The difference between the two histories in Figure 5 is large, statistically significant, and positive.

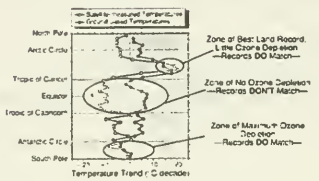

Figure 7.

Figure 7. Does ozone depletion explain the difference between ground-measured and satellite temperatures?

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tume of air 60 miles on a side and about five miles deep. Typically, two satellites are orbiting the earth continuously, providing *four measurements per day at nearly every single spot on the earth*. The instruments that perform this remarkable task are microwave radiometers. They sense the very small amount of microwave radiation emitted by oxygen in our atmosphere. Fluctuations in the levels of emitted microwave radiation are directly proportional to temperature changes of the air.

SATELLITE TEMPERATURES IN 1995

The satellite measurements indicated 1995 to be the eighth-warmest year since the record began 17 years ago. Thus, on a globally averaged basis, 1995 was a very average year. The regional temperature patterns for 1995 (Figure 1) reveal that the only areas with temperatures more than 1°C above normal were located over extreme northern Canada and the adjacent waters of the Arctic Ocean, as well as central Eurasia. Cooler-than-normal conditions existed over scattered portions of the globe such as Africa, India, China, and western Australia.

Individual months, of course, can be very different from this annual average picture. This is especially true of the winter months, when cold air masses building up over the high-latitude continents do battle with the warm oceanic air masses, and often invade each other's territory. For instance, January and February of 1995 saw extreme warmth over northern Canada and Russia, with local one-month anomalies exceeding +6°C. April 1995 had similar warmth covering most of the Arctic Ocean. August of 1995 was at least 2°C above normal over the midwest and Great Lakes states of the United States. The eastern United States was as much as 4°C below normal in November of 1995. Finally, as if to scroll at the report that 1995 was the warmest year ever in the thermometer record (which did not include December data), the satellites observed the largest one-month drop in Northern Hemisphere temperatures between November and December 1995.

THE LAST 17 YEARS

The monthly global average temperatures since January 1979 (Figure 2) reveal considerable year-to-year fluctuations. These are due mostly to climate events named El Niño and La Niña. These are opposite phases of a tropical oscillation in winds and temperature. During El Niño, weaker than normal winds in the tropical eastern Pacific allow warm water to build up and transmit its warmth to the atmosphere. Strong El Niños can disrupt weather patterns around the world. During La Niña, unusually brisk surface winds cause enhanced upwelling of cool water from the depths of the eastern Pacific and depress air temperatures.

The other dominating effect on global temperatures is the volcano. Two major eruptions have occurred while the satellites have been operating: the Mexican volcano El Chichon early in 1982, and Mt. Pinatubo in the Philippines in June of 1991. For two or three years after explosive volcanic eruptions, sulfuric acid aerosols drift through the lower stratosphere and reflect a small amount of sunlight back into space. This sun shield was likely responsible for the very cool summer experienced in the northern United States in 1992. The warming trend between 1992 and 1995, then, was the result of the dissipation of the Pinatubo aerosol layer.

But changes are in the wind. Note that the last two months in Figure 2 (December 1995 and January 1996) were unusually cool. Sea surface temperature observations during this time suggest that a cool La Niña is returning to the Pacific for the first time since 1989. At this point, 1996 is shaping up as another year without much warming.

WHAT ABOUT GLOBAL WARMING?

In the context of global warming, the average trend in the satellite record during 1979-1995 is a cooling of -0.05°C/decade, with an uncertainty of about ±0.03°C/decade. If the effects of volcanoes, El Niño and La Niña are removed, the adjusted trend becomes about +0.07°C/decade. This is just beneath the range of the latest global warming projections of +0.08°C to +0.30°C, and far beneath the range for the model that served as the basis for the Rio Treaty on Climate Change. When will the satellite measurements match global warming rates predicted by computer climate models? Maybe when those models are improved to the point where they contain all of the temperature-stabilizing processes that exist in nature.

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Spencer, R.W., and J.R. Christy, 1990. Precise monitoring of global temperature trends from satellites. *Science*, 247, 1558-1562.

east coast—was associated with a vortex expansion, not a contraction. Here is a classic example of an extreme weather event that can be explained by circulation changes unrelated to global warming.

What about hurricanes? The very active Atlantic tropical storm season in 1995 prompted the now far-too-common outcry that this is caused by global warming. Examination of the trend in tropical storms and hurricanes over the last half-century shows no trend at all (Figure 8).

Typhoons, the Pacific cousins of hurricanes, are much more common because of the larger available pool of warm water in the huge Pacific basin. The average number of tropical storms in the Pacific is 27.5, and, as in the Atlantic, there is no trend (Figure 9).

SUMMARY

Emissions of anthropogenic greenhouse gases continue to increase rapidly. Atmospheric trace gas concentrations have gone halfway toward a doubling of pre-industrial concentrations. It is not only logical, but imperative, that the climate record be scrutinized to find evidence of the impacts of these gases.

Careful examination of the atmospheric circulation record shows no evidence of a greenhouse-warming signal. In January, when the signal should be strongest, the Northern Hemisphere vortex has expanded—exactly the opposite of what models and theory indicate should occur. This particular expansion was associated with a more meridional flow pattern and a related increase in extremes—more cold air masses extending farther south over the eastern half of the United States, more warm air in Alaska, and an increase in the strength of nor'easters. Furthermore, this meridional flow pattern is not new; a very similar situation existed prior to the 1930s when the cause could not have been greenhouse gases.

Climatic change is natural and, at present, unpredictable. We are currently in a general pattern that produces more extreme conditions. There is substantial evidence that circulation patterns shift abruptly from one regime into another, and these sudden changes can occur at any time. Until theory and models advance to the point that they meld with historic observations in a systematic fashion, it is unwise to attribute any particular weather event, series of weather events, or weather in a year or series of years, to global warming.

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GCM prognostications of climate change in the southern Great Plains region should be viewed with extreme caution.

Despite great advances made in climate modeling over the past decade, it appears that the models are still unable to accurately simulate regional-scale precipitation and to agree on regional changes that may result from a doubling of atmospheric trace gas concentrations. If we remember that precipitation is affected by and, in turn, affects the simulation of virtually every other atmospheric variable, precipitation is useful to examine the overall predictive ability of a GCM. At present, existing models are unable to represent adequately the present-day precipitation climate. Therefore, it seems premature to base policy and economic decisions on the results of these models.

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if the models do not adequately simulate precipitation patterns, soil moisture errors are created immediately. If the soil moisture is not properly represented, the surface energy balance is miscalculated, and the near-surface air temperature error increases. This new error initiates feedbacks into evaporation processes and infrared radiative transfers, and on and on. As this simple example shows, small errors in the model are compounded by numerical representations of feedbacks that underlie the climate system, and these relatively small, but compounding errors seriously compromise the predictions of temperatures long into the future.

The Hadley Centre scientists are to be commended for their quality modeling efforts. These scientists know the strengths and weaknesses of both the design of the numerical model and its ability to replicate the climate of the past century. However, the more one compares the model outputs to the observed climate variations, the less agreement exists between the two. The Hadley Centre experiments may be fantastic achievements in applied atmospheric physics, computer science, and applied mathematics, but little confidence should be placed in their climate prediction for the middle of the next century.

If the models are correct, humanity has a problem on its hands, and substantial changes in climate can be expected to occur in the coming decades. If we choose to believe in the near-surface global air temperature estimates, recent warming and record-breaking temperatures would support the low-end model predictions. Examination of the satellite-based global temperatures or the radiosonde measurements suggests that the atmosphere is not behaving according to the numerical climate models, and that the threat of global warming is relatively small. Regional climate patterns, particularly the lack of warming in the Arctic, also argue against the greenhouse threat.

Continued combined efforts between the numerical modelers and the scientists dealing with historical records of climate will prove extremely useful in determining the fate of the climate system in the next century.

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April 3, 1996

Dr. Robert T. Watson
Associate Director, Environment
Office of Science & Technology Policy
Old Executive Office Building, #494
Washington, D.C. 20502

Dear Dr. Watson:

I want to extend my appreciation to you for your recent testimony before the Committee on Science regarding Global Change and the Earth Observing System.

Enclosed are some additional questions intended to clarify certain issues. I request that you provide written responses to these questions by May 1. Your responses will be made a part of the hearing record. If you have any questions, please contact Dr. William Smith of my staff at 202/225-4439.

Once again, thank you for your participation in this important hearing.

Sincerely,

George E. Brown Jr.

GEORGE E. BROWN, JR.
Ranking Democratic Member

Enclosure

QUESTIONS FOR DR. WATSON

1. Several times during the hearing, witnesses suggested that the USGCRP is funded at a level of $2.2B. Could you please clarify what the budget is of the USGCRP, as their annual report indicates that the request for FY-96 is only about $1.8B and the appropriation is somewhat less than this amount?

2. There seems to be some confusion over the term "consensus," it seeming to imply that every person is in agreement whereas what the IPCC seems to provide a range of estimates that encompasses most qualified opinion, with some outliers on both sides. Could you please explain your understanding of the word consensus as used in the IPCC context.

3. Dr. Michaels indicated that in 1992 a test was not done comparing the transient model simulations against the observed climate. You suggested that the "cold start" problem was likely one reason. Could you please elaborate and indicate any other reasons that the comparison was not done?

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20500

May 6, 1996

The Honorable George E. Brown, Jr.
Ranking Democratic Member
Committee on Science
U.S. House of Representatives
Suite 2320 - Rayburn Building
Washington, DC 20515-6371

Dear Representative Brown:

On April 3, 1996, you sent three additional questions to Dr. Robert T. Watson, Associate Director for Environment of the Office of Science and Technology Policy, to clarify certain issues that arose during a hearing of the Committee on Science at which he testified. As you may know, Dr. Watson resigned from the Administration on April 30, 1996, to accept a position with the World Bank. He completed the answers to your questions before leaving the Administration, and I am forwarding the enclosed answers on his behalf. Please let me know if I can be of further assistance.

Sincerely,

Rosina M. Bierbaum
Acting Director for Environment

Enclosure

Question 1:

Several times during the hearing, witnesses suggested that the USGCRP is funded at a level of $2.2 billion. Could you please clarify what the budget is of the USGCRP, as their annual report indicates that the request for FY-96 is only about $1.8 billion and the appropriation is somewhat less than that amount?

Answer:

The USGCRP appropriated budget for FY95 was approximately $1.8 billion. The FY96 appropriated budget is also approximately $1.8 billion, and the FY97 budget proposed by the President is approximately $1.9 billion. This budget is made up of programs and numerous activities at the sub-program level spread across multiple agencies. It should also be noted that the overall budget appropriation for Federal environment and natural resources research was approximately $5.4 billion in FY 95, and is approximately $5.2 billion in FY 96, with approximately $5.4 billion proposed by the President for FY97. Some of the activities supported by these funds are certainly relevant to global change research, even though they are not formally counted as part of the USGCRP. It is possible that some of the witnesses were including some portion of these funds in asserting a $2.2 billion funding level.

Question 2:

There seems to be some confusion over the term "consensus," it seeming to imply that every person is in agreement whereas what the IPCC seems to provide is a range of estimates that encompasses most qualified opinion, with some outliers on both sides. Could you please explain your understanding of the word consensus as used in the IPCC context.

Answer:

As a scientific and technical assessment body, the role of the IPCC is to bring together the full range of contributors to the research literature relevant to climate change in order to evaluate the agreements and disagreements in findings reached by different scientists. The process naturally involves a great deal of debate over the details of various interpretations of theory, data, etc. The IPCC authors, in presenting the results of this evaluation to the policy community, seek to convey broad areas of agreement whenever possible. But where disagreements exist these are clearly presented. The range of views is sometimes expressed through discussions of alternate viewpoints or through a range in some quantity, e.g., the projected range of temperature change over the next 100 years (1 - 3.5 degrees Centigrade).

Within the IPCC, a scientific consensus is most easily reached when a finding is supported by multiple independent lines of inquiry. An IPCC consensus statement describes the view which can be supported by the large majority of participating scientists. Striking an appropriate and widely-agreed upon balance, which conveys an accurate sense of the range of opinion about what we know and what we don't know and the key uncertainties has been a challenging aspect of achieving consensus in the preparation and review of the IPCC reports. It is important to emphasize that the IPCC does not seek agreement on some least common denominator conclusion.

Question 3:

Dr. Michaels indicated that in 1992 a test was not done comparing the transient model simulations against the observed climate. You suggested that the "cold start" problem was likely one reason. Could you please elaborate and indicate any other reasons that the comparison was not done?

Answer:

The transient model simulations to which Dr. Michaels refers were run as a test of models for the case of a 1% per year increase in future carbon dioxide concentrations. The idea was to test a group of models against the same plausible, simple future scenario. If identical input to a group of models resulted in widely varying results, it would demonstrate conceptual problems with the models. In other words, the simulations were intended and designed to test the ability of the group of models to simulate a hypothetical climate rather than the observed past climate. Because of this, and several additional reasons elaborated upon below, these particular model simulations cannot be meaningfully compared to the observed record of past changes in temperature.

First, the simulation used a carbon dioxide increase of 1% per year which may be roughly appropriate for the future assuming no emissions limitations, but is clearly significantly too high for the past 100 years (the period of the global data set) and even too high for the last 17 years (the period of the satellite data). The rate is too high, even when allowance is made for the increase in all greenhouse gases. Furthermore, the simulations did not allow for the observed increase in the atmospheric concentrations of aerosols, which tend to exert a cooling influence on the atmosphere, both regionally and hemisperically. Thus, the forcing scenario is about a factor of four times too high compared to the past 100 years.

Second, at the beginning of model simulations some general circulation models only respond slowly to the increase in the

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concentrations of greenhouse gases: the so-called cold start problem. Thus, care must be taken to compare simulations with the observations in the early years. This is a particularly important for comparing observations and simulations over short time periods and for particular decades.

Third, the Earth's climate exhibits natural variability because of changes in solar radiation, volcanic eruptions, and the exchange of energy between the atmosphere and the oceans. The global mean surface temperature can vary naturally by several tenths of a degree Centigrade over a period of a few decades, both regionally and hemispherically. Hence, it is not possible to simply compare observations to a single simulation of the response of the Earth's climate to a change in greenhouse gas concentrations, because the simulation cannot take into account the initial state of the ocean-atmosphere system.

Dr. Michaels attempts to overcome these difficulties by making a number of assumptions and adjustments, all of which are questionable. He attempts to stretch out the simulation in time to allow for the difference between the simulated and observed rates of increase in greenhouse gas concentrations, and he attempts to associate a particular time of the simulation with specific years. In addition, he ignores the natural variability of the system, ozone depletion, anthropogenic aerosols, volcanic perturbations, and El-Nino events. Hence, Dr. Michaels is failing to account for known natural and anthropogenic effects that would obscure the greenhouse signal.

Finally, many of Dr. Michaels' comparisons are between observed changes in surface air temperature and the 17 year Microwave Sounding Unit (MSU) temperature record, which is a measure of the air temperature between 5 and 30 thousand feet rather than of surface air temperature. It is difficult to compare these two records, which are not and should not be the same, for a number of reasons. Even greater care must be taken in comparing model simulations with the MSU record.

When newer, more sophisticated model simulations that include aerosol effects are carefully compared with the observational record, taking into account the factors discussed above, there is encouraging agreement between the models and observations.

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